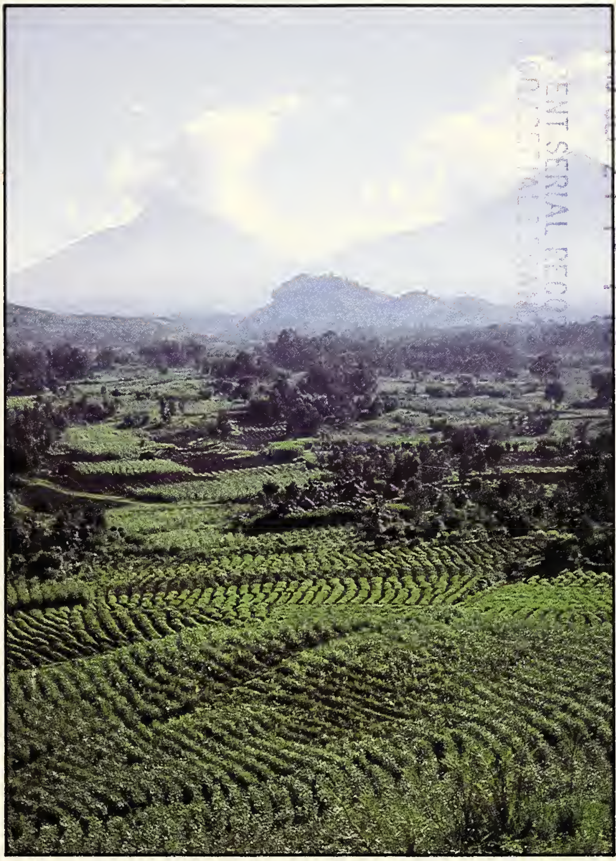
Soil Resource Inventories and Development Planning

Proceedings of Workshops at Cornell University 1977-1978



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Soil Management Support Services

Soil Resource Inventories and Development Planning

Selected Papers from the Proceedings of Workshops organized

by the

Soil Resource Inventory Group

at Cornell University, April 4–7, 1977, and December 11–15, 1978.

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Foreword

A knowledge of soil resources is important for planning agricultural development. Many developing countries do not have a comprehensive soil resource inventory. Others have information on land which only partially answers questions critical for the evaluation of the environment. In other cases, complete surveys are available but ignored because of lack of communications, differences in technical language, or in disciplinary approaches. As a result planners have difficulties selecting suitable locations for agricultural development, or deciding on the best uses of land being brought into cultivation.

It is hoped that this book will be useful to soil scientists and planners in improving communications between disciplines. The text is a selection of papers presented at two workshops held at Cornell University in 1977 and 1978. The workshops concentrated on the characterization of soil surveys and on ways to make them more effective for agricultural planning.

The workshops were organized by the Soil Resource Inventory Group in the Department of Agronomy at Cornell University. These activities were supported by the United States Agency for International Development under a 211(d) grant to Cornell University. The AID Development Support Bureau encouraged and stimulated interest in a better knowledge of soil resources and in more efficient methodologies to obtain and use this knowledge.

Contributions to these efforts from scientists abroad are acknowledged with thanks; without their cooperation this publication could not have accomplished the objectives it intended to serve.

The Soil Management Support Services Project (SMSS) of the Soil Conservation Service in the U.S. Department of Agriculture is now continuing the study of new methodologies in soil surveys. The materials published in this book may serve as starting points for further research on inventory techniques particularly suited for developing nations. It is hoped this publication will be a source book for direct application in SMSS's technical assistance programs.

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Soil Resource Inventory Group

1977–1978

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Opening Address

R. W. Arnold

We are extremely pleased that each of you has been able to come here for several days. Just as spring is arriving and flowers and buds are utilizing stored energy to confirm and renew hope eternal in a world facing difficult decisions, so this workshop will draw upon your storehouse of knowledge to reassure the world that pedology offers strength and hope as a part of the solution to land use problems. The dynamic processes of springtime integrate many aspects of an environment and only through their interactions do we see the brilliant transformations. As a working group we can only concentrate on several components of land use; however, a consensus concerning the role of soil resource inventories will contribute to meaningful expressions of renewed hope for our fellow human beings.

Our longer range objective is to assist others in developing feasible soil survey strategies to meet planning objectives that affect land use, primarily in developing countries. Thus we are concerned with the items or aspects that improve the effectiveness of soil resource inventories.

The U. S. Agency for International Development has a long history of concern for the "small farmer" and the improvement of his status in his economic, social, and political environment. Because of his small parcels of land, it is often not possible to provide information adequate for improved performance of these individual tracts of land. However, most users of land throughout the world respond to policies and land use decisions made by various government agencies. These policies may include project development, price supports, forms of credit, production goals, marketing procedures, infrastructure, industrial growth, and balance of payment schemes. These are the constraint systems within which all farmers operate. It seemed reasonable to us that better decisions and policies should result from better communication and interchange between pedologists and land use decision makers.

TWO-STAGE PROGRAM

1. The first stage is to gain a better understanding of properties and qualities of soil maps and soil surveys. What are the characteristics associated with these aspects? This consequently provides pedologists and others with the knowledge of constraints, limitations, and potentials related to providing soils information.
2. The second stage will involve working with planners who make different kinds of decisions that affect land. We hope to match their ideas, needs, and constraints with the potentials of soil resource inventories so they can decide on the alterna-

tives that improve the cost-effectiveness of soil survey effort. The purpose of this workshop is to focus more on the first stage—that is, what do we know about soil maps and what additionally do we need to know? A portion of the workshop will discuss the use of soil survey in the planning process — mainly as viewed by pedologists. A later workshop will concentrate more on planning as viewed by non-pedologists.

THE TASK AHEAD

We have invited each of you because of your interest and expertise in pedology. We are asking for your help in sharing thoughts in this endeavor. Each of us has more expertise in some areas of concern than others, and by teaming up we hope to strengthen all of our viewpoints and bring to light a more solid understanding or comprehension of problems and solutions in evaluating soil resource inventories.

Underlying the unique vantage point that each of you has is the knowledge of repeating and consistent aspects of soil inventories which are shared in common. These underlying concepts and principles are the ones that must be given attention in designing and evaluating soil surveys.

It is exactly these concepts that we hope to bring out and try to unify during our few days together because we want to be able to provide information on alternative solutions and provide guidance to the agencies of less developed countries in their endeavors to develop and strengthen their own programs of soil and land resource inventories. We do not envision our role as telling others what to do—rather we want to bring together information that will make their tasks easier and hopefully not repeat the costlier mistakes of our own experiences.

How well we succeed likely depends on our abilities to provide proper information, training materials, self-help guidelines, and ideas that are logical, reasonable, and useful in evaluating available data and in designing more effective soil resource inventories in the years ahead.

Experts in pedology are truly exceptional people. You are not possessive of your ideas and concepts; you are dedicated to understanding the environment; you are humanitarians with a genuine concern for the world community. You are unselfish with your time and talents, and you certainly aren't afraid of hard work. We are grateful that each of you has become one of these experts. In addition to doodling on pads of paper we want you to jot down concerns and comments about each subject area of our discussion groups because Wednesday morning we will ask for your recommendations about where we are and where we ought to be going.

The approach of the Cornell group up till now has been directed to some problems of appraising the utility of soil maps. There are, of course, many ways to conceptualize the problems and many places to begin. We started with soil maps because they are often the most conspicuous product presented for obtaining information about an area. Actual decisions are most commonly based on other maps whose information is derived from the soil map; consequently we felt it was imperative to know about soil maps.

Professor Cline has been instrumental in guiding our recent thinking; that explains why we sent you a copy of his ideas. His article is also the first under the Cornell contributions. In essence there are two leading questions:

1. What does one need to know to appraise the soil itself for use and management?
2. To what degree does a soil map and associated materials provide the things we need to know?

Each of these is really a generator of sets of related questions for which we are seeking guidance, judgments, advice, and consensus of expert opinion. We are painfully aware that most aspects are inter-related and can seldom be adequately considered out-of-context. Nevertheless it appears that the big picture can only be handled by focusing attention on specific parts long enough to bring out the principles needed to abstract the essence of the smaller parts.

WORKSHOP FORMAT

The main emphasis of this workshop is to identify those items necessary to evaluate soil resource inventories. On one hand we have some maps and reports already available—many of which defy classification by current concepts—and on the other hand are those items needed to produce soil information in the years ahead that will be used to advantage in policy making and land use decisions.

This workshop will consist of eight areas of concern. Each session will begin with two or three presentations of about 15 minutes each, highlighting the subject and providing us with ideas for the discussion groups. We are together here as specialists in pedology; we don't have to impress others of the significance of our work—we already know this. Consequently I charge each of you to remember that each person here is generally familiar with your subject matter and some of your personal contributions to pedology. Believe me, we are impressed, and that is exactly why you are here. The presentation sessions are the prelude to the time when each of us must give our best effort in evaluating what needs to be known and approaches for obtaining this information. The discussion group periods do not last very long but they are the heart of this workshop.

Unfortunately we must try to maintain a fairly rigid timetable. There are happily no such schedules in the evenings and we hope you take that time to discuss further or follow up on the hundreds of ideas you have about pedology.

The eight formal sessions are given in your outline. They are:

1. Orders of soil surveys—kinds, objectives and interpretations of different types or kinds of soil surveys.
2. Evaluation of soil surveys and maps—what attributes need evaluating, what is quality and effectiveness, and what about map unit accuracy.
3. Soil survey methodology—case studies.
4. Soil survey methodology—techniques: using Landsat, designing survey legends, airphoto and other remote sensing techniques.
5. Review of methodology of evaluating soil map characteristics—some results of the Cornell group.
6. Soil properties important for given land uses — soil and land qualities, trace elements, and other considerations.
7. Soil data presentation—what can we do to help different users understand and take advantage of soil information.
8. The role of soil surveys in the decision-making process for development planning—the effects of scales and legends, and the role of soil surveys.

You will hear more about Session 9 later. It will be a time to draw together the many ideas into recommendations and guidelines for proceeding further with soil resource inventory evaluations. You will need to consult your own notes as we try collectively to be of assistance in looking at where we are and how to move ahead.

There is a chairman for each presentation session. Following each session we will break up into three discussion groups. These are all listed—with the discussion leader, secretary and participants. Our group assignments were picked at random; there was no bias toward any of us. Our sincere thanks to each of you for being here to assist in our deliberations.

Objectives and Rationale of The Cornell Study of Soil Resource Inventories

M. G. Cline

The participants in this workshop are well aware that soil resource inventories vary enormously in approaches, detail, and quality. Probably all also appreciate the fact that neither the agencies which make soil inventories nor the institutions and individuals which use them have developed comprehensive methods to evaluate their usefulness for the varied purposes to which they are applied.

The problem is especially serious in the developing nations. Many of the soil survey programs are relatively new, and experience with both making and using soil inventories is limited. Resources for the work, including qualified soil scientists, are commonly limited. Administrative authorities responsible for policy and allocation of funds rarely appreciate what is needed to conduct a soil survey and to achieve and maintain quality. Funds for correlation, even within countries, for example, are rarely available, and quality control is severely restricted. This is not to imply that soil inventories in developing nations are necessarily poorly planned and executed. Many excellent surveys have been made. But the obstacles are very great, indeed, and the usefulness of many soil inventories has suffered as a result. The utility of many of these is not enhanced by the fact that they are made without clearly defined applied objectives beyond the general idea that knowing what kinds of soil exist is important for a nation's development. Too commonly, soil inventories are treated essentially as ends in themselves, assuming that they can be used in some way for practical purposes.

It was against this background that soil scientists who work in the international area at Cornell and representatives of the Agency for International Development concluded that some method should be developed to appraise the usefulness of soil surveys and similar soil inventories. They were particularly concerned because people who are not expert in soil science are among the more important audiences for whom soil inventories are made. Yet these people have little or no basis for judging whether or not inventories important for their purposes are, indeed, suited to their objectives. Soil scientists have the expertise to make such judgments, but even they have developed no standardized method of appraisal.

Initially the objective of the project was to develop a method suitable for people who should use soil inventories but do not have expertise to appraise them. It quickly became evident that the theory and principles on which a sound method should

be based had not been articulated. Consequently, much of the effort to date has focused on principles and theory. This workshop will concentrate more on the primary objective.

SCOPE OF THE STUDY

In earlier discussions with individuals and groups, it has been evident that the objective of appraising the utility of soil inventories is easily confused with soil survey interpretations for evaluating suitability of soils for use. It must be clearly understood that this sutdy is concerned strictly with whether or not a soil inventory provides soils information in an amount and form that permits evaluation of suitability of the inventory for land use objectives. The actual prediction of soil performance and suitability for use from soil inventories is a separate and distinct operation.

The study has focused on the utility of soil resource inventories of developing nations. The principles involved, however, should also apply to the inventories of developed countries. Consequently, the study has drawn on data derived from soil inventories in developed as well as developing nations. The criteria for appraisal of soil inventories should apply to both, with appropriate modification in detail for differences in land use objectives.

The study has concentrated on the use of soil inventories (1) for predicting soil performance in the production of plants for food and fiber, and (2) for land use planning in which food and fiber production is a major element. Many of the principles involved in appraising the usefulness of soil inventories for these kinds of land use objectives should, however, be valid for diverse purposes, such as appraising utility for urban development planning and understanding ecology of the environment. Different kinds of information would have to be considered, but the principles should be the same.

Soil resources constitute only one of several factors that determine land use potentials. Accessibility, cultural factors, economic considerations, and others are also primary determinants of the feasibility of a given kind of land use. The SRI study has been confined to the appraisal of soil inventories as the basis for evaluating only the soil factor in land use potentials, deliberately avoiding confounding the soil factor with other factors on which final land use decisions must also be based.

RATIONALE OF THE STUDY

The following pages abstract the primary ideas that determined the course of the study. Relevant lines of reasoning are indicated, but details of the study's accomplishments to date are beyond the scope of this paper.

The study treats soil resource inventories primarily as documents that record the geographic distribution of unique kinds of natural soil bodies on maps and identify the sets of properties which characterize them in accompanying legends and texts. It does not exclude inventories that identify areas defined in terms of single soil properties or inferred attributes, but it does not emphasize them. It focuses on inventories that identify soils in terms of some soil taxonomy, but it does not exclude others.

Soil resource inventories are, at best, incomplete records of the soil conditions that exist within land areas. Their potential usefulness depends on the degree to which they

identify the soil conditions that are critical for given land use objectives and accurately show their geographic distribution on maps. Their actual utility also depends on presentation of this information in a form that can be used effectively. Starting from these relatively obvious truisms, the study addressed two questions: (1) What would one need to determine in an on-site appraisal to predict soil performance? (2) What attributes of soil maps and associated legends and texts must be appraised to determine the degree to which a soil inventory provides that information in a form that will satisfy land use objectives?

The study identified five kinds of information that would be necessary to predict soil performance in an on-site appraisal:

1. The land use objective for which soil resources are to be evaluated.
2. The level of detail of information that would be required to evaluate soil resources for that objective.
3. The soil properties that would be critical for the projected land use.
4. The degree of limitations which critical soil properties would impose on that use.
5. The effects of the geographic distribution of limiting soil conditions on the projected use.

It is necessary to identify land use objectives of item 1 to establish requirements of items 2 through 5. In an on-site investigation, an appraiser tests soil conditions in the field against use limitations of items 3 through 5 in the detail that land use objectives dictate to be necessary for item 2.

The information required to predict soil performance from inventories is, obviously, the same as that required for on-site investigations. A major part of the appraisal of utility of soil inventories consists of testing the adequacy of information they give for items 3 through 5 as listed above and the detail of item 2 against those requirements for each land use objective. In addition, however, the ease or difficulty of extracting soil inventory information and its reliability relative to actual field conditions are potent factors affecting the usefulness of any inventory. Thus, the study has addressed three additional criteria:

6. Quality of the base map, including ground control.
7. Legibility of the map.
8. Reliability of the recorded data of both the map and the associated text.

The perspective in which the study has considered these eight elements is discussed briefly in the following pages.

Land use objectives

Land use objectives for which soil resource inventories are used differ widely in both kinds and levels of generalization. Both affect the information a soil inventory must provide. For example, some objectives require prediction of soil performance for specific plants, such as maize, rice, or cacao. Others require prediction of soil suitability for general land use classes, such as cropping, grazing, or forestry. Still others require evaluation of soil resources for alternative uses in land use planning. Different kinds of land use objectives, such as these, require different kinds or amounts of information about soils and their geography.

To complicate the problem further, some kinds of land use objectives require site-specific predictions for small areas, such as individual fields. Others require broad

generalizations about extensive areas hundreds or thousands of square kilometers in size. Such differences in scale dictate different levels of detail or generalization of the information about soils and their distribution. The study has concluded that there is no viable alternative to identifying minimum requirements of kinds, amounts, and detail of soil information for each contrasting kind and level of generalization of land use objectives, against which the information of soil inventories may be tested for appraisal of their usefulness.

Detail of information

This element includes both (1) the number and size of delineations on a soil map, and (2) the detail in which soils of mapping units are identified and described in the legend and text. Both must be appraised in terms of the degree to which they satisfy requirements of the land use objective for which a soil inventory is appraised.

Map scale is one criterion of map detail, but it is not infallible. Some soil maps are at scales larger than necessary to present the information they obtain. Others are at scales too small to present the information legibly. The study proposes that the smallest scale at which map data can be presented legibly is a more useful criterion than the scale of publication. It determines the minimum size of legible delineations and, therefore, the smallest land area about which predictions can be made. It and related criteria developed by the study do not measure how much of the geographic pattern of soils in the field is represented on the map. That can be inferred from the character of mapping units identified in the legend, although field investigations may be needed for precise estimates.

Kinds of mapping units, the level of detail of soil classification in the legend, and the detail in which mapping units are described in the text have as much impact on usefulness of a soil inventory as the detail of the soil map. Many soil inventories of developing nations do not give enough information about the map units to realize the full potential of the map. The study has identified four criteria of the legend and text that should be used in conjunction with scale when appraising the level of detail of a soil inventory:

1. ***Kinds of mapping units.*** Are they defined as predominantly one kind of soil or as mixtures of two or more kinds? This is a criterion of the detail of information on the map relative to soil pattern in the field. It controls detail of geographic location of soils.
2. ***Taxonomic level of taxa used to identify map units.*** This identifies the level of detail or generalization of information about soils in delineated areas. It controls the details of predictions about the soils.
3. ***Phase and other qualifying terms in names of map units.*** These add definitive criteria and increase the potential detail and precision of predictions about the soils of map units.
4. ***Soil properties and inferred attributes described in the text.*** The extent to which the text amplifies information which can be implied about map units from the legend is an important criterion of the detail of information a soil inventory provides. Both soil descriptions and the amount and character of inclusions in map units rank high among the kinds of information which should be provided in the text.

Soil properties

Ideally, the text of a soil inventory should describe the properties which have been observed or measured for each kind of soil. These descriptions provide the basic data

from which soil limitations and suitabilities for use can be deduced. Many soil inventories provide inadequate soil descriptions. Some give none at all.

In the absence of adequate soil descriptions, the names of mapping units can be used to deduce sets of soil properties in combination. These names commonly identify taxa in some taxonomic system. In some systems, the names imply specifically defined ranges of properties. In others, the names suggest only very general concepts of soils related to assumed genesis or factors of soil formation.

A high level of expertise in soil science is required to deduce information about soil properties from taxonomic names. If people who are not expert in soil science are to appraise the usefulness of soil inventories, there appears to be no alternative to compiling lists of the soil properties implied by the names of taxa of each major taxonomic system likely to be encountered. This should not be an impossible task, especially within a single country where only one system may be used. Phase or similar qualifying terms used with names of soil taxa add important information about soils and commonly are self-explanatory.

In some soil inventories, the names of map inits stand for sets of properties unrecognized in any taxonomy. In others, the map units are named in terms of physiography, vegetation or other features that are soil-related but not consistently diagnostic of soil properties. Unless the soil properties associated with such terms are described, even soil scientists are unlikely to deduce consistently useful information from them with a high degree of confidence.

Soil limitations

The utility of a soil inventory depends heavily on the extent to which it permits one to identify those soil attributes that limit soil performance. These are sometimes called "performance attributes." Some of these attributes are observed or measured soil properties, which should be recorded in soil descriptions. Soil depth, acidity, and slope are such properties. Others must be inferred from descriptions of soil properties. Periodic wetness and available moisture capacity, for example, are commonly inferred though not observed directly.

Ideally, the text of a soil inventory should describe such potentially limiting attributes for each kind of soil. This kind of information is commonly incomplete in soil inventories of developing nations. If potentially limiting attributes are not identified, the expertise of a soil scientist is usually necessary to deduce those which must be inferred from soil descriptions. For those who lack that expertise but need to know whether or not the information can be extracted from a soil inventory, it should be feasible to compile a list of common limiting soil attributes showing the soil properties from which they can be inferred.

Each land use objective has a set of limiting soil attributes that are critical. These differ in both kind and level of detail among uses. The study has developed checklists of limiting soil attributes for eight types of land use objectives. The information provided by soil inventories can be compared to these lists to determine deficiencies. Similar checklists could be developed for most land use objectives.

Geographic distribution of limiting soil attributes

For some purposes, the geographic pattern of contrasting soils is equally as important as limiting attributes or the area affected by them. Five percent of wet soil in a field otherwise well suited to mechanized farming, for example, may be no more than a

nuisance if it is all in one place. It can control choice of crops, cultural operations, and timeliness of work if it is distributed in small parcels thoughout the field.

The study has considered this topic in terms of criteria for judging how well the soil map segregates and describes the geography of the total soil variation of an area.

Map units characterized as single kinds of soil-consociations. Although such units contain inclusions of other soils, their performance attributes that can be identified should be uniform enough that predictions based on them should apply to entire delineations for practical purposes. Any contrasting inclusions that would affect such predictions should be identified and described in terms of amount and pattern of distribution.

Map units characterized as mixtures of contrasting soils—associations and complexes. Such units permit predictions about performance of each of the constituent soils as accurately as if the soils were delineated separately. They do not show precisely where those predictions apply within delineations. They are suitable for estimating amounts of soils that perform differently if the units are properly defined in terms of proportions. They can be evaluated in terms of general suitability for land use objectives that are not site-specific. Description of the pattern of constituent soils and of inclusions adds predictive value.

The remaining soil variation that is not identified in map unit definitions. Map units identified in terms of taxa of higher categories of a taxonomy, for example, tell little about the geography of limitations imposed by properties that are criteria of lower categories. Predictions that depend on them cannot be made.

Beyond these criteria, anyone appraising the usefulness of a soil inventory should search the text for information that describes the geography of soil-related conditions which may not be recorded for map units. Description of the variation of rainfall or temperature within an area, for example, is a good indicator of soil moisture and temperature regimes.

Quality of the base map

A soil map has little value for most uses if the soil boundaries cannot be located with reasonable accuracy in relation to landmarks and cadastral reference points. The study has considered in great detail the amount and accuracy of ground control for soil maps at various scales. Guidelines for appraising the adequacy of base maps have been developed.

Legibility of the map

Legibility is a primary factor determining the ease with which a soil map can be used and, indeed, whether it will be used at all. The study has developed a number of criteria for appraising legibility following investigation of a number of factors that influence legibility on existing maps, including:

- Size of delineations
- Number of delineations per unit area
- Color or other devices to distinguish among delineations or to present interpretive groupings
- Amount and legibility of ground control of the base map
- Quality of reproduction

Reliability of the information

The value of a soil inventory for any use obviously depends on how accurately the information it provides represents actual soil conditions in the field—called "ground truth." Few soil inventories are totally unreliable, but many contain information that should be questioned. An appraisal of the utility of a soil inventory should include an estimate of the reliability of both the cartography and the identification and definition of soils. This is emphasized, for if the apparent quality of a soil inventory based on a study of maps, legends, and texts in the office does not, in fact, reflect faithful characterization of ground truth, the information is not only useless but deceptive and potentially harmful.

The ultimate test of reliability is determination of ground truth in the field. The study has investigated methods for determining ground truth in considerable detail, including statistical bases for sampling designs and for interpreting results.

In lieu of field testing, potential reliability can be inferred from the methods used to collect the information. Generally, potential reliability decreases in the order in which inventory methods are listed below (the methods as defined in the 1951 *Soil Survey Manual* of the U.S. Department of Agriculture):

1. Detailed field methods with remote sensing support.
2. Detailed field methods without remote sensing support.
3. Reconnaissance field methods with remote sensing support.
4. Reconnaissance field methods without remote sensing support, or
   Remote sensing with field checking.
5. Exploratory field methods, without remote sensing support, or
   Remote sensing without field checking.
6. Schematic compilations without field work.

Any information given in an inventory about procedures, such as density of traverses and sampling intensity, is a valuable criterion. None of these criteria, however, measure human error.

Poor reliability related to human error, incompetence, or dishonesty is difficult to establish without determination of ground truth. Experienced soil scientists can detect evidence of poor reliability from the map and text. Such evidence as identification of soils in places where they are not likely to be found, boundaries that do not conform to diagnostic landscape features, and statements or soil descriptions in the text which are inconsistent with known facts indicate human error or incompetence. If they are numerous, the reliability of the entire inventory must be questioned. Existing geological surveys, topographic maps, and other information about an area can be used to detect inconsistencies in comparison with soil maps and texts.

APPLICATIONS OF THE STUDY

Development of a comprehensive method by which people without expertise in soil science can appraise soil resource inventories remains the primary objective of the study. Much remains to be done to translate the principles which have been developed into methodology that can be understood and can be applied empirically by this important group of people. This appears to be a goal that can be attained. As the foregoing discussion would imply however, such methodology will have to be based on

a much simplified interpretation of the principles developed, and it will undoubtedly lose precision and scope in the simplification. Nevertheless, it should be an enormous improvement over no basis at all.

Given widespread circulation of the results and interpretations of them, the impact of the study on soil scientists may be more significant than the appraisal method, *per se*. It should organize ideas about soil inventory utility in one comprehensive treatment for soil scientists generally and for those in developing nations in particular. It should spur some soil scientists to scrutinize their own inventories critically. It could inspire soil scientists of some developing countries to develop methods for evaluating their soil inventories, methods that could be designed for the local environment and could be much simpler than a comprehensive system. This may well be the best way to reach people who lack expertise in soils in some countries.

Finally, and perhaps most important, the study pinpoints attributes of soil inventories that detract from their usefulness. Those who scrutinize the documents which come from the study should recognize in them the bases for guidelines for designing new soil surveys. Guidelines of various kinds have been developed, but this study focuses on the consequences of poor design and execution. It should affect the scrutiny to which new soil survey plans are subjected by both soil scientists and the administrative officers responsible for allocating funds.

PART ONE

SOIL RESOURCE INVENTORIES

Section I
Kinds and Intensities of Soil Surveys

Soil Survey: Different Types and Categories[1]

G. Aubert

Soil is a natural object, and as such, it is an indispensable object of study, both as an entity itself and to understand the action of its formative factors in order to determine its genesis and evolution, its place in a natural and rational classification, and its global distribution.

Since soil is one of the fundamental components of terrestrial ecosystems, we must therefore attempt to ascertain how soil interacts with them. These ecosystems are often transformed directly or indirectly by man into agro-ecosystems which furnish food, fiber, and other products such as textiles, wood, oil, etc. The study of soil types must therefore be performed with the goal of determining their possible adaptation to these utilizations.

Soil survey, the field and subsequent laboratory study of soils, is based on grouping individual soils into units defined by their characteristics, properties, and evolution, elements which permit the expression of their specificity, the role they play in ecosystems, and their possibilities for utilization. Mapping is performed to show the spatial distribution of these defined units.

OBJECTIVES AND TYPES OF SOIL CLASSIFICATION FOR USE IN SOIL SURVEY AND MAPPING

As mentioned above, the fundamental objective of soil survey is to define map units by classifying grouped elements that are a function of soil characteristics, their relationship with the environment and their evolution. These map units may be ultimately expressed as a distribution on a rational map.

Soil surveying and mapping on a pedological level

Classification. The various categories of soils do not always correspond to natural classification units, which for practicality must not be extremely complex; consequently, they do not always represent the range of natural variability. Frequently a classification system is the basis of a soil legend: this legend can include *intergrades* or *taxadjuncts,* units related genetically to the pure units which form the real framework of the survey site.

The representation of complexes on soil maps is a difficult problem to resolve. Whatever may be the legend and scale of the soil map, there are varying numbers of

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areas containing such numerous and intricate soil units that it is impossible to accurately represent the exact position or area of each of the units, regardless of whether the survey was sufficiently detailed to locate them with precision.

Several solutions to this problem are possible, and their applicability depends on the scale of the map and its objective. In the case of interpretive pedological maps with scale ranges of 1:500,000 to 1:5,000,000, one could try to represent the most characteristic soils, even at the risk of exaggerating certain points and not representing others. For medium scale maps, (1:50,000 to 1:200,000, and occasionally 1:500,000), which are suitable as a regional planning base, the method utilized is entirely different. Here, cartographic units correspond to soil associations. Sometimes it is possible to replace these simple, most utilized soil complexes with toposequences, or successions of toposequences, or even catenas of soils. This last method is the most satisfactory, especially for determining more explicit applications for regional planning. First, it is necessary to show the existence and extent of these catenas. Already the utilization of toposequences in areas where they are developed greatly improves the cartographic representation of the soil survey results, and allows the faster production of more informative maps. In large scale maps, the same complex units are employed, but their proportion with respect to "pure" units is normally more limited, if the survey was sufficiently precise and detailed.

Factors of formation. In surveying, the relationships between the kinds of soil and their various factors of formation and evolution assume great importance. Often it is essential to make these characteristics a component of the system, especially for intermediate map scales. In the French classification system the characteristics of parent material are included at the family level. Vegetation and geomorphology parameters are not incorporated in the definition of soil, except for their occasional use at the series level (where judgments based on the criteria of soil depth are more effective). However, the cartographic regrouping of soil units can be accomplished based on the consideration of these two factors, which are themselves consequences of soil genesis. As did Tricart (1974), Kilian (1974) defines cartographic units on the basis of geomorphology. Under this premise, it seems preferable to regroup soils into landscapes in which their distribution and relationships are more precisely shown in detailed maps (Eschenbrenner and Badarello, 1975).

Pouget (1977) has integrated the study and representation of vegetative groupings and soils, in surveying soils of the steppe areas of Algeria; this permits him to create for a medium scale of 1:100,000 a more complete map illustrating the potential uses of landscapes.

Another procedure is to include on each page of the map itself, small scale schematic diagrams showing the general distribution of the genetic factors: geomorphology, vegetation, climate, etc. This has been done with the French soil maps at the 1:100,000 scale and the New Hebrides soil maps.

Soil surveying and map-making for utilization

The knowledge of soils and their properties, process of formation, and distribution is generally required only for formulating plans for soil utilization. Usually this utilization is agricultural development, although at times it is for public works or urbanization (including recreational areas), for the preservation of the ecosystem and its integral complexity, or for environmental goals (to create reserves, national parks, etc.). It is very certain that if the evaluation of suitabilities or limitations of a soil with respect to a

certain type of use depends initially on the soil itself, its characteristics and properties, and often its process of formation and evolution, this evaluation must also place particular importance on diverse factors (geomorphological and topographic conditions, vegetation, etc.) and consider certain of its environmental elements, and even general or local conditions that are exterior to the soil itself (for example, technical or socio-economic conditions) (Brinkman and Smyth, 1973). These last factors have great temporal variability and consequently the possibilities of integrating them into maps are limited because with the time and cost considerations involved, the results should be representative for as long as possible.

Diverse methods have been proposed to accomplish the transition from surveying to graphic representation of the soils' possible use.

1. Synthesized. The interpretation of the accumulated knowledge of soils and their environments, in the context of the latest agronomic techniques and local ecological conditions, can be expressed in a synthesized manner. In certain cases this can be represented as explanatory paragraphs on the fertility and utilization of each soil unit, or as a summarizing chapter in the text of the soil survey report. This has been frequently effected during the O.R.S.T.O.M. studies in tropical Africa and in Maghreb (Maignien, 1969 and Segalen, 1970).

Usually however, it seems most effective to report the results obtained on a map called optimum utilization (a term previously used by Aubert and Fournier, 1954; Riquier, 1954; etc.) or cultivation potential of the land. These are qualitative agronomic terms that express the data of a pedological map either generally or as a function of local soil-based recommendations for crop groupings or land use types. In effect, the level of fertility of a parcel may be very different, as may be its cultivation or use potential, depending on its assignment to annual crops, tree crops, pasture, or forest. Besides the agricultural categories, recommendations could be made for the assignment of a certain field to recreational or industrial installation areas.

In arid regions, the development should be considered with and without the presence of irrigation. Aside from the soil map or cultivation potential map, a map of potential productivity indicating cropping possibilities following improvements such as drainage, removal of calcareous crust or other activities could be compiled (Vieillefon, 1967; Riquier, Bramao, and Cornet, 1970). This kind of interpretation must consider not only soil characteristics, but also environmental ones: slope, degree, danger of erosion, and even vegetative cover. Maps which depict these factors must be based on studies made with a very large scale, or marginally with a medium scale.

2. Analytical. The interpretation of soil maps for agronomic planning or for more general area land use planning must be analytical. The method may be parametric, given the utilization of complex indices with weighted parameters based on ecological zones, principal crops, and envisaged uses (Riquier, 1974).

More commonly, the method is simply analytical, or essentially based on values obtained for relevant soil characteristics (such as depth, texture, pH, etc.), environmental characteristics (for example slope), or for a combination of characteristics (perhaps erodibility), which are judged to have primordial importance for agricultural development or generalized land uses. These characteristics and especially the limiting values, or thresholds, vary as a function of local climatic conditions.

Such factors can be depicted in the format of analytical maps (of texture, hydrodynamic properties, permeability, etc.) (Lévêque, 1975), cultural constraint maps or as soil resource maps (Boulet, 1976 and Fauck, 1977).

3. Interpretative. Interpretation, irrespective of whether it is interpretative or analytic, may also be thematic or designed for a particular type of use, especially cultivation. This form of interpretation is often of transitory value due to the tremendous control external factors such as economics, problems of location, etc. have on the possible use of the land. For example, the suitability of land for banana production typically depends on the proximity of a shipping port or marketplace. With the inherent risks involved in this type of land evaluation, the technique is becoming progressively less utilized, despite persistent demands for it by economists. Rather this strategy has been replaced by the intermediate interpretative type of approach, either thematic or analytical (Boyer, 1974).

TYPES OF MAPS AND LEGENDS

As indicated in the preceding discussion, in most cases the results of both soil surveys and studies derived from them are expressed in the form of maps indicating the distribution of different recognized units and their relationships. Pedological and non-pedological soil maps include a vast variety of forms, but these can be distinguished by the density and precision of their detail, their scale, and their legend (Aubert and Tavernier, 1972).

Different kinds of maps as a function of the density and precision of detail contained in their information

In those regions, now globally rare, where essentially no valuable surveys of terrestrial resources exist, maps of the "probable" distribution of principal soil types expected as a function of existing information on soil formative factors (geologic deposits, climate, topography, and even vegetation), can be compiled. These maps do not have definite significance except at the scale of synthesis (1:1,000,000 to 1:5,000,000), or at medium scales (1:200,000 to 1:500,000).

Habitually, three levels of cartography are distinguished on the basis of precision, as the above-mentioned type of map is rarely encountered:

1. Reconnaissance maps. These are based on observations and results obtained from traverses conducted throughout the study region and on known elements of factors of formation, as well as relationships which have been established during the course of the investigation between the observed soils and those diverse factors . . . in particular, at the end of the study of the toposequences formed over the principal parent rocks of the area. The soil map of France at the scale of 1:1,000,000 conforms to this definition, at least for the majority of the country.

2. Semi-detailed maps. Such surveys are carried out using traditional procedures, but the precision of observation, at least theoretically, corresponds to one observation per cm^2 of the map.

3. Detailed maps. These maps are the result of very precise, detailed studies. The level of precision necessary for this category is minimally four observations for each cm^2 of the map.

Such limits of precision are very theoretical, and are hard to apply to practical situations since calculations of the gain in precision are difficult (the coefficient by which it would be necessary to divide the preceding recommendations or multiply the envisaged surfaces for a known point) due to the use of aerial photography and additional satellite imagery.

Although the use of these modern techniques permits greater rapidity and more detail in establishing the limits between the map units, it certainly needs to be supported by numerous traverses and observations of the soils.

Different kinds of maps as a function of scale

Another common habit is the classification of soil maps as a function of their field scale. However, it should be remembered that field work is often undertaken at a scale that is at least double, and preferably quadruple to, that at which the map is published. (For example, in France the field scale is 1:25,000 for a 1:100,000 published map). Classification on this basis has different potential possibilities and significance for the use of these documents.

*1. **Small scale maps.*** Maps at the scale of 1:1,000,000 or smaller permit general interpretations. As such they are of great didactic value since they permit the performance of interesting geographical studies of soils in either diverse regions or on several continents, and allow useful extrapolations about the consequences of land use, in particular agronomic use. According to our conception with respect to the French classification system, the legends of such maps can include classification levels as low as subgroups with their associated phases, and can even distinguish those families which have particular importance.

*2. **Medium scale maps.*** Scales of 1:50,000 or 1:100,000 are correlated with maps designed for regional planning. These in effect serve as a base for prospective work. In France, those at 1:100,000 have been retained simply because of the time and effort invested; those at 1:50,000 are more interesting in terms of their applications. In tropical countries a scale of 1:200,000 as in the soil map of Bossangoa (Boulvert, 1974) or 1:500,000 in the map of Upper Volta (Fauck, 1977), is more commonly utilized. Of course with the last scale, the document clearly represents an intermediate stage with respect to the preceding case.

In the legend of these maps the soil families as distinguished by the lithographic nature of the parent material can be indicated, even as can be soil series that generally correspond to significant gradations of soil depth for the land use, especially if it is principally agricultural.

*3. **Large scale maps.*** At scales larger than 1:50,000, the soil map permits practical applications for local development planning and area development. Soil series, and even phases of those characterized by different erosion intensities or internal drainage conditions, are distinguished on the legends of these maps.

Even if these two general methods of soil map classification are clearly different, their results nevertheless partially overlap. For example, maps at a scale of 1:1,000,000 or at smaller scale are in general types of reconnaissance maps if they are not really derived from a synthesis of more detailed maps, such as those at the 1:200,000 or 1:100,000 scales. Similarly, maps at larger scales are not always reconnaissance maps; rather they are more often detailed maps.

Different kinds of maps as a function of their objectives

This subject has been briefly considered in the first part of the report and specific recommendations have been given in the preceding paragraphs of the second part.

*1. **Pedological maps.*** Theoretically, for pedological maps, the kinds of maps and legends follow the rules of the precision and level of information, as a function of their scale as given in the beginning of the second part of this paper. The legend is linked as

narrowly as possible to a soil classification system, as for example, the morphogenetic (soils map of France) or morphological (soil map of the U. S.) classification systems.

2. Regional planning maps. In the last several years, it has become increasingly more apparent that representation of the milieu at a medium scale (1:100,000 or 1:200,000) is insufficient as a basis for regional planning. The global characterization of the evolution of diverse soil types, their distribution, and even their relationships with various factors will not suffice for a general description of the milieu for expressing the general possibility of its use. Thus various authors have attempted to accomplish the objective at this level by presenting maps that are both pedological and morphogenetic.

Without remaining at the initial stage of French soil maps where geomorphological descriptions do not appear except in the form of accessory maps at a smaller scale, nor proceeding to the morphogenetic maps (such as those prepared by Tricart and Kilian) in which soil characteristics appear only in a secondary form, the methodology of Beaudou and Chatelin (1976) can be followed: A description of the pedological regions, followed by pedological soil landscapes, and finally functional segments or elements of toposequences and catenas of soils. Eschenbrenner and Badarello (1975) used schematic drawings to describe and explain morphogenetic landscapes of the northern Ivory Coast (Odienne region).

In this method, the landscapes are defined by the presence of characteristic morphological elements: inselbergs, residual relief, buttes (which are generally cupped with ironstone), the remains of plateaus, derived forms more or less flattened or convex with an appearance of the slopes of lower bottoms, and nick-point values. Landscapes are also defined by the relative importance of soils at the level of the subgroup and their associated phases, and even of the families.

Maps of grouped morphopedological landscapes have been constructed at the scale of 1:200,000; but each of them is supplemented by a pedological detailed map, at the scale of 1:50,000, which is representative of a typical landscape, and by corresponding airphotos.

3. Maps of agronomic application. As has been previously stated, maps of agronomic applications can be very different, both in their detail and scale, but they must be based on a soils map established on an identical or larger scale.

a. Maps of soil resources are established at smaller scales (such as the 1:500,000 map of Upper Volta), and they are analytical in nature. They include delineation of agro-climatic zones and emphasize texture, primarily that of the surface horizon, but also that of the lower horizon to the extent that it affects plant performance. Taxonomic units are indicated with respect to the principal kinds of improvements proposed for various characteristic features: drainage conditions, actual water consumption, organic matter content, exchangeable bases, physical properties (particularly unfavorable ones), and the presence of toxic elements.

Some subunits are defined by the association of different component units in a zone or "spot" of the soils map, as this had been indicated in the units of the pedological map.

In northern climatic zones, cultivatable lands have been separated into areas suitable for dryland and irrigated agriculture and rangelands. On the map itself, a table was compiled that indicated the order of the units and subunits as assembled on the pedological map, and these units were given values characteristic of the various land uses for each of the retained fertility factors.

b. At medium and detailed scales (1:100,000) or larger, synthesized maps of optimum agricultural utilization or suitability for cultivation are assembled. The legend

includes units of "universal agricultural value" and the principal possible uses as a function of the soil characteristics themselves (their type of evolution, parent material, depth, etc.) and also as a function of their environment, slope, degree of erosion, etc.

The most interesting system (such as the one utilized by Roederer in Tunisia), as previously mentioned, indicates for each unit of land the relative fertility for each of the principal kinds of use or possible cultivation groupings, and the principal forseen improvements. It is of course indispensable that these documents be prepared with collaboration of an agronomist.

An example is given by the management maps compiled for the high-plateau steppes of Algeria which were prepared by Pouget (1977) in collaboration with geomorphologists, botanists, and agronomists. The maps include recommendations and forseen management and the potential yield of forages.

c. Maps of cultivation constraints have been rarely established by French pedologists, as many of the previous map types include in their taxonomic descriptions constraints such as "utilizable depth" or various other unfavorable physical properties.

However, maps have been made for the northern Cameroons by P. Brabant that analyze depth, texture, profile differentiation, insufficiency or excess of available water, and degree and danger of erosion. They have also been made in France by the "Organization for the Management of the Hills of Gascogne." The limiting factors are primarily the slope and the depth of usable land, and extreme textures, the excess of calcareous materials and any fertility or chemical insufficiencies.

d. In France, purely thematic maps are also established at very detailed scales with regard to drainage operations (various working groups of INRA), or for particular irrigated cultivations (Organization for the Management of Lower-Rhône Languedoc). The maps compiled at very small scales (1:1,000,000 or 1:5,000,000) concerning the dangers of desert formation and the degradation of soils [R. Pontanier (1976) in Tunisia] and the salinity of soils [Aubert (1977) for Africa] can also be included.

CONCLUSION

I would like to point out some of the main fundamental problems that keep soil survey from better achieving its objectives.

1. We need an improved soil classification as a basis for the map legends, especially for the small scale general soil maps.
2. For medium scale soil maps we have to work on a better use of the geomorphological soil characteristics of the landscapes for the definition of the soil complex units.
3. For detailed soil maps at the large scale level we have to give more regular definition of the soil series and their phases, to get an easier interpretation for land utilization.
4. For agricultural use interpretation we need a more precise study of the relations between soil properties—mostly physical properties and the yields of main crops of various ecological zones.
5. For general land use, we need to work on the most important soil conditions for every type of non-agricultural use.

BIBLIOGRAPHY

Aubert, G. 1977. Carte des sols salés d'Afrique (scale 1:5,000,000). p. 598–604. *In* Managing saline water for irrigation. Proc., Int. Soc. Soil Sci. Texas Tech. Univ., Lubbock, TX.

Aubert, G., and J. Boulaine. 1967. La Pédologie. Press Univ. de France, Paris, France.

Aubert, G., Ph. Duchaufour, and V. Oudin. 1950. Carte des sols de France. École Nat'l. des Eaux et Forêts, Nancy, France.

Aubert, G., and F. Fournier. 1954. Carte d'utilisation optimum des sols. Sols Afr. 3:83–109.

Aubert, G., and R. Tavernier. 1972. Soil survey. p. 17–44. *In* Committee on Tropical Soils (ed.) Soils of the humid tropics. National Academy of Sciences, 2101 Constitution Ave., Washington, DC 20418.

Beaudou, A. G., and Y. Chatelin. 1976. Methodologie de la représentation des volumes pédologiques. O.R.S.T.O.M., Adiopodoumé, Côte d'Ivoire.

Boulet, R. 1976. Carte des ressources en sols de la Haute Volta. Ministry of Cooperation and O.R.S.T.O.M., Paris. (5 sheets, scale 1:50,000).

Boulvert, Y. 1974. Carte pédologique de la province de Bossangoa (Republique Centrafricaine).

Boyer, J. 1974. Interpretative land classification in French speaking countries. p. 26–34. *In* Approaches to land classification. Soils Bull. No. 22. F. A.O., Rome.

Brinkman, R., and A. J. Smyth. 1973. Land evaluation for rural purposes. Int. Inst. Land Reclamation and Improvement, Wageningen, The Netherlands.

Eschenbrenner, V., and L. Badarello. 1975. Carte des paysages morphodédologique 1/200,000. Odienne O.R.S.T.O.M., Adiopodoumé, Côte d'Ivoire.

Fauck, R. 1977. Carte de ressources en sols de Haute Volta. O.R.S.T.O.M. (In press.)

Food and Agriculture Organization (FAO). 1974. Approach to land classification. Soils Bull. No. 22. F. A.O., Rome.

Food and Agriculture Organization (FAO). 1976. Framework for land evaluation. Soils Bull. No. 32. F. A.O., Rome.

Kilian, J. 1974. Etude du milieu physique en vue de son aménagement. Agron. Trop. 29 (2–3):141–153.

Lévêque, A. 1975. Carte des potentialités agricoles de la zone B de l'Est Mono (Togo). O.R.S.T.O.M., Rome.

Maignien, R. 1969. Manual de prospection pédologique. Initiations-Documentations Techniques No. 11. O.R.S.T.O.M., Paris.

Pontanier, R. 1976. Monographie sur la désertification. O.R.S.T.O.M., Tunis.

Pouget, M. 1977. Etude agropédologique de la région de Messad (Algerie). D.E.M.R.H.—O.R.S.T. O.M., Paris. (1 sheet, scale 1:100,000).

Riquier, J. 1954. La carte d'utilisation des sols à Madagascar. Comptes rendus, 2ème Conf. Interafr. Sols (Leopoldville). 2:1189–1200. Brussels.

Riquier, J. 1974. A summary of parametric methods of soil and land evaluation. p. 47–53. *In* Approaches to land classification. Soils Bull. No. 22. F. A.O., Rome.

Riquier, J., D. H. Bramao, and J. P. Cornet. 1970. A new system of soil appraisal in terms of actual and potential productivity. F.A.O., Rome.

Segalen, P. 1970. Pédologie et développement. Techniques rurales en Afrique 10. Ministry of Cooperation, Paris.

TRICART, J. 1974. De la geomorphologie a l'étude écographique intégrée. Agron. Trop. 29 (2–3):133–140.
VIEILLEFON, J. 1967. Etudes pédohydrologiques au Togo. Vol. II. F. A.O., Rome. (1 sheet, scale 1:50,000).

The Objectives of Soil Surveys of Various Intensities

A. J. Smyth

No attempt is made here to review the extensive literature related to this subject nor is the treatment intended to be comprehensive. The viewpoint is essentially personal and, hopefully, provocative.

In general, it may be stated that the objective of soil survey is to obtain a better understanding of spatial changes in the characteristics of the soil continuum so that soils may be used more efficiently for the benefit of mankind. The information obtained by soil surveys contributes to comparisons of environmental situations so that experience may be exchanged. It is also used directly as a guide in planning land use for agriculture, and increasingly, for engineering purposes.

Soil survey data has long been regarded as providing a foundation on which land development can be constructed. This paper ends by suggesting that it is more realistic to see soil data as a part of the physical ceiling beyond which present technology does not allow us to pursue objectives generated by social, economic, and political pressures.

TERMINOLOGY

Experience suggests that discussion of different "kinds" or "orders" of soil survey is often hampered by misunderstanding arising from different interpretations of the terminology.

Table 1 presents a system of terminology developed within FAO specifically to assist international discussion of this topic (FAO, 1969). Table 2 presents additional information that places this terminology in clearer perspective.

It will be noted that the terminology is based on intensity of observation. Terms such as "detailed," "semi-detailed," and "reconnaissance" are avoided because they carry a wide variety of connotations. Furthermore, the detail and to a large extent the scale of soil survey maps are matters of convenience within constraints of accuracy determined by the intensity of observation.

A terminology based on observation intensity is equally appropriate whether the soil survey data is presented in mapped or tabular form.

Such terminology is not inherently meaningful, however, as a guide to the objectives which a soil survey will serve. Clearly, the exact density of observation required for a

Table 1. Terminology of soil survey intensity in relation to final mapping scale and kind of mapping unit (based on FAO, 1969).

Kind of Survey	Range of Scales	Kind of Mapping Unit
Very High Intensity	Larger than 1:10,000	Phases of soil series; soil series; occasionally soil complexes
High Intensity	1:10,000 to 1:25,000	Phases of soil series; soil complexes
Medium Intensity	1:25,000 to 1:100,000	Associations of soil series; physiographic units (enclosing identified soil series)
Low Intensity	1:100,000 to 1:250,000	Associations of Great Soil Groups; occasionally individual Great Groups; phases of Great Groups. (Alternatively, land units of various kinds enclosing identified Great Soil Groups)
Exploratory	1:250,000 to 1:1,000,000	Land units of various kinds (preferably enclosing identified Great Soil Groups)
Syntheses	Smaller than 1:1,000,000	Great Soil Groups and phases of Great Groups (having essentially taxonomic significance)

certain interpretation will vary from one environment to another particularly in relation to the complexity and degree of contrast of the soil pattern. There is also wide variety in the possible nature of observations, which can include:

1. Observations to characterize soil units, involving detailed study of morphology and sampling for physical and chemical examination (usually soil pits);
2. Routine observations to establish kinds of soils and to check on homogeneity within identified units (usually auger borings);
3. Rapid bores to check boundary locations; and
4. Special observations including deep boring in irrigation/drainage areas, infiltration tests, conductivity measurements, neutron probing, etc.

Thus, the specifications of a soil survey should describe the nature as well as the density of observations.

BASIC RELATIONSHIPS BETWEEN OBJECTIVES/INTENSITY/SCALE IN SOIL SURVEY

The practical applications of soil surveys of various intensities have been described in many publications and, in general terms, are well known. A detailed general account is given by Stobbs (1970) and Bie and Beckett (1970) have reviewed soil survey practice in many countries.

Table 2. Additional information on soil surveys of various scales (FAO, personal communication).

Kinds of Survey	Scale	Area Represented by 1 cm^2 of map	Density of Observations[a] (0.5 obs./cm^2 of map)	Approx. Average Rate of Progress[b] (per 2-day month)	Accuracy of Boundaries
Very High Intensity	1:5,000 1:10,000	0.25 ha 1.0 ha	1/0.5 ha 1/2 ha	500 ha 800 ha	Position of all boundaries checked throughout length on the ground
High Intensity	1:20,000 1:25,000	4.0 ha 6.25 ha	1/8 ha 1/12.5 ha	1,250 ha 1,500 ha	Position of almost all boundaries checked throughout length on the ground
Medium Intensity	1:50,000	25.0 ha	1/50 ha	75 km^2	Some boundary checking—most inferred
Low Intensity	1:100,000	1 km^2	1/2 km^2	200 km^2	Almost all boundaries inferred

[a]Density of observations: figures represent the density of all soil observations averaged over the entire area of the map (acceptable density usually ranges between 0.25 and 1.0 observations/cm^2 of map on this basis).

[b]Rate of progress: figures given represent an approximate average from the wide range of progress rates experienced in actual surveys.

In the context of developing countries the purposes of the kinds of survey distinguished in Table 2 can be summarized as follows:

Syntheses. Final mapping scale usually less than 1:1 million; promoting public awareness (teaching, conservation campaigns, etc.); some direct practical value at global and international levels of planning.

Exploratory studies. Final mapping scales usually between 1:1 million and 1:250,000 but occasionally much larger; preliminary identification of areas having high development potential or serious development problems; occasionally for testing soil classifications.

Low intensity soil survey. Final mapping scales usually between 1:250,000 and 1:100,000; national level solutions to the problems "WHAT TO DO" and "WHERE ELSE TO DO IT" in agricultural development; assessment of possibilities and priorities in use of limited manpower and facilities.

Medium intensity soil survey. Final mapping scale usually about 1:50,000; regional solutions to the question "HOW?" in agricultural development; adequate for implementation of less intensive forms of land use (e.g., some forms of forestry and grazing) and for planning broad agriculture/urban zonation.

High intensity soil survey. Final mapping scales usually between 1:25,000 and 1:10,000; precise local solutions to the questions "WHERE" and "HOW" in the context of rain-fed arable development; may be an adequate basis for implementing irrigation and even for some engineering decisions in uncomplicated situations.

Very high intensity soil survey. Final mapping scales less than 1:10,000; suitable as a basis for planning implementation of sophisticated agricultural schemes, including irrigation, and to assist engineering decisions in areas where soil pattern is complex and soil differences significant.

An excess of observations is not only needlessly expensive but it also complicates data storage and analysis. There is a real danger that superfluous data will obscure information of special interpretative value. This is perhaps especially true of excessively detailed descriptions of soil morphology and squirrel-like accumulations of soil chemical data. Whether the computer can lead us back out of the maze which our enthusiasm sometimes creates remains unproven.

To the author's knowledge all aid agencies recommend to less developed countries that they should undertake soil studies in a systematic sequence of surveys of increasing intensity. The logic of this approach, as a means of ensuring that limited specialized manpower and facilities are concentrated in the most promising areas, requires no elaboration. It is interesting to note, however, how few of the "developed" countries have adopted this approach systematically themselves. Several are suffering the consequences; having mapped substantial areas in detail they find themselves constipated with data, unable to see the panorama for the pedons.

If low intensity studies show that the pattern of soils is complex and that the soil differences are significant in relation to the likely development objectives then the need for soil surveys of high intensity is established. How intensive should they be?

The answer to this question is inextricably related to the choice of final mapping scale, for a mapped presentation of data relevant to detailed planning problems is nearly always required. Many extraneous factors such as the scale of available air photography or of base maps or the mere availability of cartographic facilities often have a crucial bearing on the choice of mapping scale but, in an ideal world, this author thinks that two factors deserve special consideration: (1) the required precision of soil boundary placement, and (2) the likely minimum area of planning interest.

The first factor reflects the relationship between soil characteristics and development objectives. In a prospective irrigation scheme, for example, knowledge of the distribution of marked contrast in the hydraulic characteristics of soils needs to be precise if it is to assist the design of canals and drains. In other contexts, the precise position of soil changes will usually be much less significant. It is worth noting that the value of precise mapping of soil boundaries is qualified by the likely accuracy with which these boundaries will be relocated on the ground when the map is put to use.

The minimum area of planning interest can be defined as the area within which practical considerations of management dictate that farming practice (or, more broadly, *land use*) must be uniform. In practical terms, which allow for some exceptions, this is the smallest area of land that can be usefully differentiated on an interpretative soil map. It should not occupy less than 1 to 2 square centimeters of the map, if the map is to be used conveniently. This means, for example, that a planner interested in soil units as small as one hectare requires maps of 1:10,000 scale or larger.

Not all of the information needed to determine the minimum area of planning interest will be available in advance of a soil survey, but an educated guess can usually be made in consultation with agricultural economists and other specialists. A great many physical, social, and even political factors of the environment are involved in this assessment.

A CLOSER LOOK AT THE OBJECTIVES OF SOIL SURVEY

Beckett (1971) in a paper on the cost-effectiveness of soil survey defined the aim of a soil map and its memoir as:

> "to equip the user to make more precise or more accurate statements about the soil conditions at any site of interest, or to make statements with less expense or trouble, than would have been possible without such map and memoir."

As Beckett and his colleagues have demonstrated in a series of valuable papers, a definition of soil survey objectives in terms of discrete statements provides a basis for quantitative comparison of the effectiveness of different methods and intensities of soil survey. These papers have emphasized the assessment of purity of the mapped soil unit as a quantitative measure of the accuracy and reliability with which statements about the soil and its properties/potential can be made (see Bie and Ulph, 1972, and its attached list of references). No less important, however, than the reliability of a statement is its practical significance, particularly in relation to other statements that might need to be made about site environment. The range of possible significance of different statements about soils is very great especially in the context of surveys of differing intensity.

A major difficulty for users of soil information is to separate the statements that are significant to their problem from those that are not. The solution of this difficulty should be amongst the objectives of soil survey.

The extent to which soil conditions are likely to influence agricultural development planning depends on the level of generalization at which decisions have to be made. Normally at national level (low intensity studies) the controlling environmental influences on decision making are firstly climate and secondly, landform. In medium

intensity studies (say 1:50,000 mapping) landform often remains predominant and even in very localized investigations surface slope, rather than internal soil characteristics, may largely determine the distribution of agricultural possibilities. The boundaries on soil maps, especially small scale soil maps, often represent a synthesis of detectable information on climate, landform, and vegetation as well as actual observed data on soils. In labelling such maps "soil maps" the surveyor should consider his objectives carefully to ensure that he is not chauvinistically obscuring the most directly valuable information.

From the late fifties onward soil surveyors have grown increasingly conscious that their work should serve immediate practical objectives as well as contribute to basic scientific knowledge. They recognized that amongst other things this called for improved communication with potential users of soil maps and memoirs and the surveyors devised ways of synthesizing their statements about soils in terms of land capability and suitability classifications.

A TREND TOWARDS MORE DYNAMIC LAND CLASSIFICATION?

In the seventies growing recognition of the urgency of development needs in the Third World seems to have outpaced growth in development activities. By creating a demand (sometimes unbalanced) for action rather than further studies, this situation has placed an emphasis on immediate practical objectives that amounts, in some countries, to disillusion with the long-term soil survey objectives of the past.

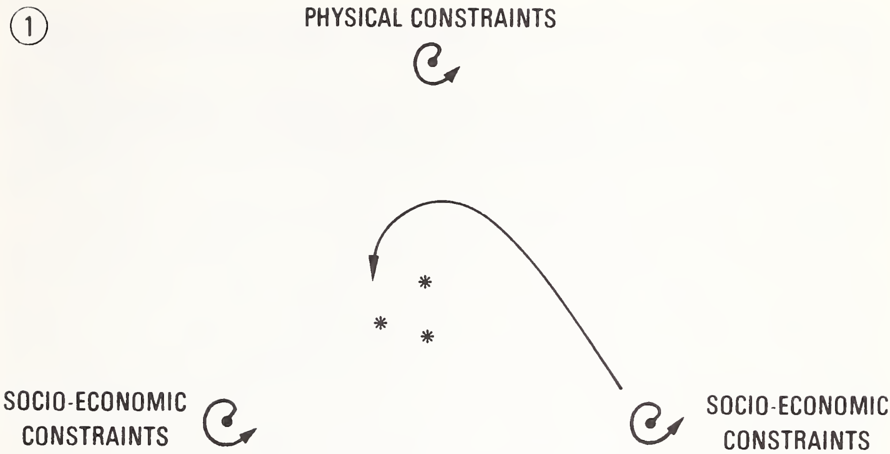
Concurrently, development attention has focused perforce on the agriculturally marginal areas of the world. Economic production in these areas often depends upon effecting change in the land resources themselves. Frequently it is change in the fertility, salinity, drainage, or droughtiness of the soils that is feasible. Thus, the capacity of a soil to be changed becomes a major consideration of soil survey interpretation; indeed the main focus changes from the static and the long term to the dynamic and the short term. Hopefully, soil surveys can be adjusted to meet both short- and long-term objectives, for soil surveying is too expensive to be repeated at short intervals.

Figures 1 and 2 simulate dynamic and static approaches to land classification, respectively. In Figure 1 feasible land use alternatives (shown by asterisks) lie within a "field" determined by three main constraints: physical constraints (or land qualities), socio-economic constraints, and sociopolitical aspirations (the desires, or objectives of the people).

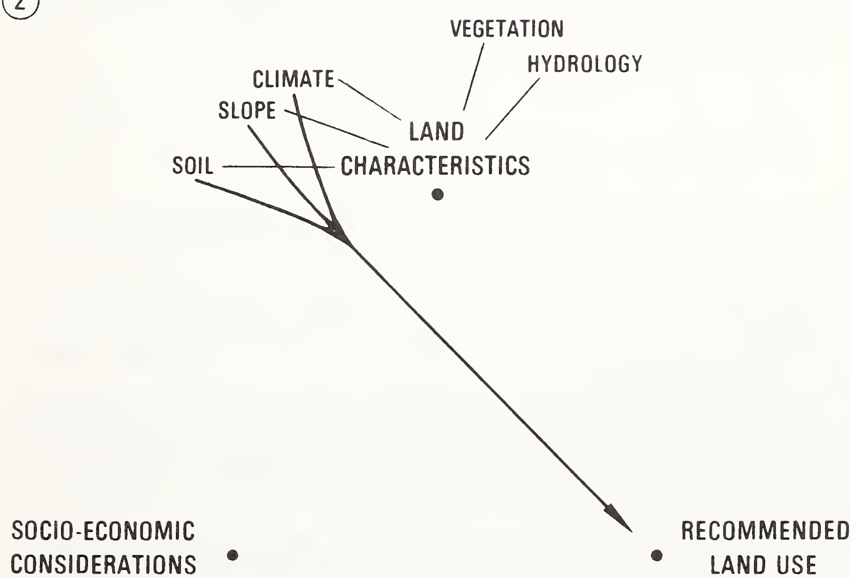
None of the constraining corners of the "field" is fixed; all can be changed. As the arrow simulates, investigation starts by establishing the desired objectives which are examined in relation to physical constraints of the land, including those of the soil. The physical constraints can be changed, however, by inputs that involve a change in the socio-economic constraints. The path of the investigation, therefore, curves in the socio-economic direction (in practice it would proceed through a series of zig-zags). To establish an acceptable compromise (a feasible alternative of land use) the originally desired objective may also have to be modified. This anticipation of change is the essence of the dynamic approach.

The principles of a dynamic approach to land classification have been outlined in the FAO *Framework for Land Evaluation* (FAO, 1976) and are presently being tested in various parts of the world.

1


PHYSICAL CONSTRAINTS
SOCIO-ECONOMIC CONSTRAINTS
SOCIO-ECONOMIC CONSTRAINTS

2


VEGETATION
HYDROLOGY
CLIMATE
SLOPE
LAND CHARACTERISTICS
SOIL
SOCIO-ECONOMIC CONSIDERATIONS
RECOMMENDED LAND USE

In contrast, Figure 2 simulates the static approach typified by the Land Capability Classification of the U. S. Soil Conservation Service (Klingebiel and Montgomery, 1961) and its imitators. Here the corners of the investigative field are fixed. The socio-economic constraints are frozen by assumption. Similarly, those aspects of the total reality of land that are investigated (mainly soil characteristics and climate) are considered temporarily immutable. The investigation examines the chosen land characteristics in the light of various assumptions and proceeds directly to the recommendations—an equally fixed point that substitutes for the objectives in Figure 1.

A dynamic view of land appraisal problems calls for considerable change in the objectives of soil survey interpretation. In the first place soil survey will be asked to provide only a contribution to what is essentially a multidisciplinary study. Elements of information will be needed from a range of disciplines to build up the overall appraisal. The more these elements are discrete and independent the more easily they can be rearranged as the terms of reference of the appraisal change. Land capability classes based on soil survey are altogether too complex to serve this purpose.

Secondly, instead of concentrating on solving the question "WHAT TO DO?" in terms of choice of crops or forms of land use, which used to be the main preoccupation of soil surveys in developing countries, attention will be focused more and more on "HOW?" to achieve an aim that is determined largely by human interests, perhaps despite the physical environment. Understanding of soil has special importance in this context for of all the many aspects of land, soil is the most amenable to change by man, for better or for worse.

By changing the soil through labour and economic inputs new uses may be made possible or the level of production from existing uses may be raised. Above a certain level improvement will no longer be economically feasible. This is the ceiling, adjustable with time, beyond which it will usually be pointless to proceed. Contributions to a knowledge of these ceilings and of the means by which they may be approached for a range of relevant land uses can be regarded as the main short-term objective of soil survey. The long-term objective, as always, is knowledge itself.

LITERATURE CITED

Beckett, P. H. T. 1971. The cost-effectiveness of soil survey. Outlook Agric. 2:191–198.

Bie, S. W., and P. H. T. Beckett. 1970. The costs of soil survey. Soils Fert. 33(3):203–217.

Bie, S. W., and A. Ulph. 1972. The economic value of soil survey information. J. Agric. Econ. 23:285–297.

Food and Agriculture Organization (FAO), Land and Water Development Division. 1969. Soil survey and land classification required for feasibility studies of irrigation development projects. Papers presented at the 2nd Session of the Regional Commission on Land and Water Use in the Near East, Cairo, U. A. R. LA: LWU/69/4. FAO, Rome.

Food and Agriculture Organization (FAO). 1976. A framework for land evaluation. Soils Bull. 32, FAO, Rome.

Klingebiel, A. A., and P. H. Montgomery. 1961. Land capability classification. Agric. Handbook No. 210. U. S. Dept. Agric., Soil Conservation Service, Washington, DC.

Stobbs, A. R. 1970. Soil survey procedures for development purposes. p. 41–63. *In* New possibilities and techniques for land use and related surveys. Occasional Papers No. 9, World Land Use Survey. Geographical Publication Ltd., London.

Soil Resource Inventory for the Small Farmer

J. B. Collins

The world's food needs can only be met by a rapid increase in productivity per unit area of available land (Biggs and Tinnermeier, 1974; Ezumah, 1972; Reaching the developing world's small farmers, 1974). The entire agricultural system of a nation depends on the productivity of the soil. One of the world's greatest potential resources for food production is the small farmer (defined as an operator of 2–10 hectares of land who receives the majority of his food and income from agricultural products produced on this land). In most tropical countries the small farmers make up 60% of the food production sector (Biggs and Tinnermeier, 1974; Kirkwood and Dean, 1975; Reaching the developing world's small farmers, 1974). The small farmer is particularly vulnerable to any deterioration of his soil resources, for the quality of his life depends on the preservation and productive capacity of his land. Its proper use is essential to food production on a continuing basis. It is important, therefore, to increase the capability of the small farmer to evaluate his soil resources for increased food production.

The concept of a soil resource inventory for the small farmer was developed from principles used by professional soil scientists in making "utilitarian type" surveys (Guide for preparing soil survey legends, 1957; Handbook for making resource inventories, 1963; Storie, 1964). This type of survey is useful in areas where there are no modern soil surveys. The survey is the vehicle for the transfer of technology via the para-professional to the small farmer.

The para-professional can be utilized to help the small farmer to evaluate his soil resources (Kirkwood and Dean, 1975; Strickland and Soliman, 1976). A diagram of a suggested mechanism for working with the small farmer is shown in Figure 1. In preparing the para-professional to teach the small farmer, it must be recognized that few if any para-professionals will have formal training in soils, chemistry, botany and other related scientific fields. Therefore, scientific knowledge must be simplified for understanding, but without loss of accuracy. Scientific facts and principles must be presented in such a manner as to overcome communication barriers and build upon the knowlege base already possessed by the small farmer.

In teaching the small farmer to evaluate his soil resources for increased food production, consideration should be given to: (1) how soils differ, (2) how differences in soils are related to the use and management of the soils, (3) how to make a soil survey, (4) soil management principles, and (5) alternative practices and crops.

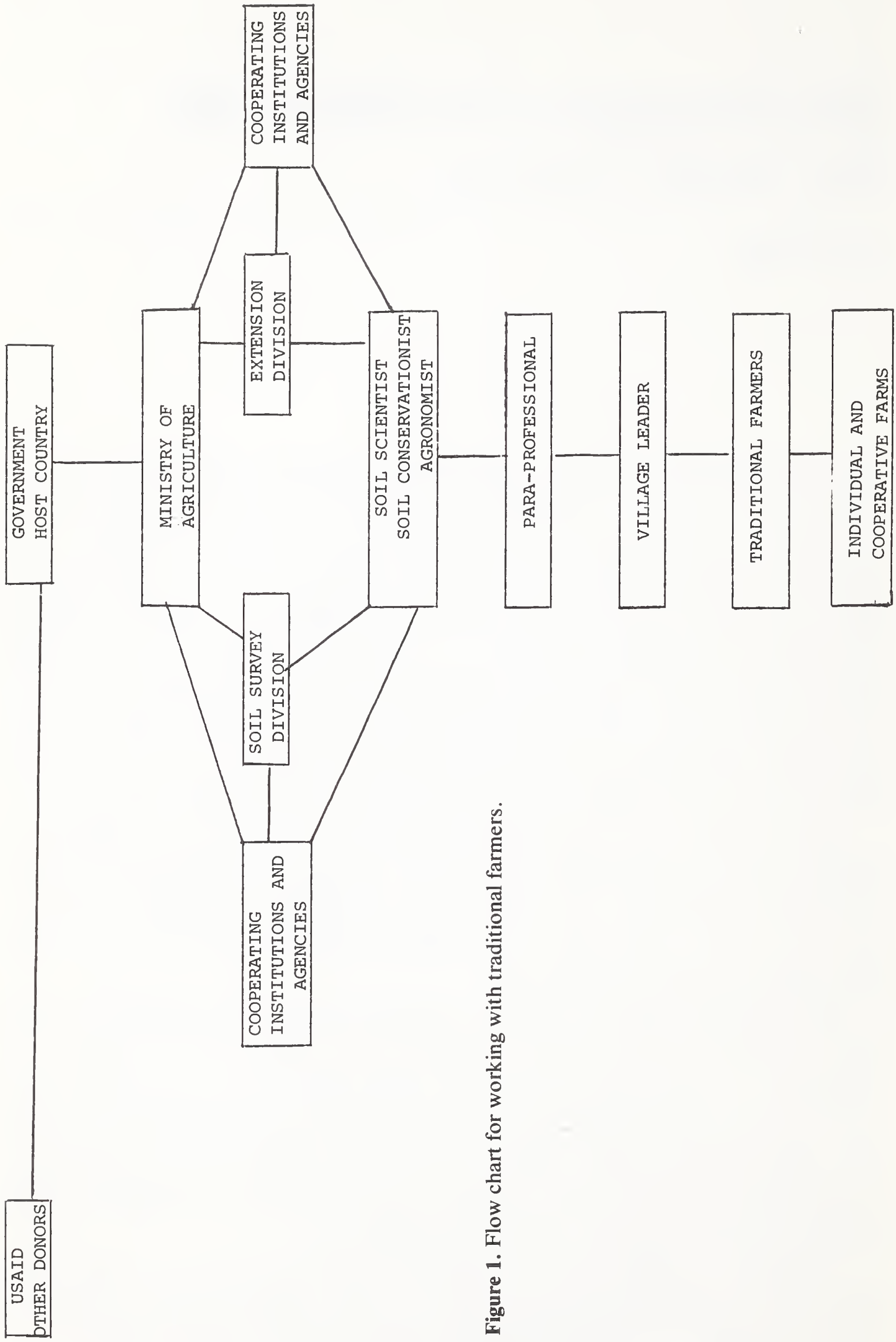


Figure 1. Flow chart for working with traditional farmers.

HOW SOILS DIFFER

There are many differences in soils that affect their use and management. These differences are of two kinds: permanent and temporary. Permanent differences are those not normally changed by management, e.g. soil depth, texture, and slope. Permanent differences form the basis for long-term plans and capability classification. Temporary soil differences are those that can be corrected by management, e.g. surface crust and traffic pans. Temporary differences tend to mask the effects of permanent differences.

Differences in soils can best be taught by on-site examination and by the use of visual aids. In teaching the small farmer how soils differ, attention should be given to the following:

Depth. Emphasis should be placed on how limited depth restricts root development and the fertility and moisture storage capacity of the soil. Actual field sites, soil profile monoliths, and soil depth charts are effective visual aids.

Texture. It is best to use only three major texture groups: fine, medium, and coarse. Demonstrate how to distinguish between each group by rubbing a moist sample between the thumb and forefinger. Actual samples of the three groups are excellent visual aids. On field trips take along samples of known textures so that comparison can be made at each stop.

Permeability. Stress the differences in soil porosity and the resulting difficulty with which water and plant roots move both vertically and horizontally in the soil. Demonstrations with actual samples and field trips are effective teaching aids.

Erosion. Stress the actual amount of soil that has been removed from or added to the soil profile. Field examples are the best visual aids. On field trips, point out the different forms (gully, sheet, rill) of erosion.

Slope. Slopes are usually quite evident to farmers. Demonstrate how to determine slope gradient with an abney hand level or a simple slope finder. Stress aspect and shape of slope. Field examples and demonstrations are the best teaching aids.

Traffic pans and surface crust. Emphasize that these differences are due to a deterioration in soil structure and that these conditions often cause widely different soils to act alike, reducing infiltration, root development, and air supply and increasing runoff. Examination of actual samples for appearance, weight, and structure is an effective teaching aid.

Natural fertility. Stress the importance of plants as indicators of soil fertility. Here again, field examples are the best visual aids.

Inhibitory and other modifiers of the field mapping unit should be explained where significant. These become more important when working with an individual farmer on his own land.

MANAGEMENT PROBLEMS CAUSED BY DIFFERENCES IN SOILS

Management problems are of a permanent nature based on the characteristics of the soils and the landscape on which they occur. This can best be taught by demonstrations and field examples. Management problems that should be considered include:

Water-holding capacity. It is best to divide the actual inches of available water that can be stored in the soil profile into three classes: low, medium, and high. This is done by

an evaluation of the various textural layers in the profile. An excellent method to demonstrate water-holding capacity is to use three small tin cans with holes punched in the bottom. Each can is partially filled with equal amounts of different textured soil material and placed in a jar. Equal amounts of water are then poured into each can. The amount of water collected in the jars illustrates the ability of each soil material to store water. Emphasis should be placed on the effects of water-holding capacity on: choice of crops, design of irrigation systems, and rainfall utilization.

Plant-soil-moisture-air relationship. Stress the need for a deep rooting zone with adequate amounts of air and water. These relationships can be easily shown by contrasting profile in the field. Monoliths of contrasting soil profiles are very effective for indoor discussions.

Fertility-holding capacity. This is a direct interpretation of the exchange capacity or the ability of the soil to store nutrients. Stress the relationship between fertility-holding capacity and the amount of nutrients that can be retained from fertilizer applications. Point out the problems associated with variability in fertility-holding capacity with increasing depths in the soil profile. The effects of organic matter, texture, and mineralogy on fertility-holding capacity can be shown effectively by the use of visual aids.

Damaging overflow. Stress how the frequency of flooding can be determined by the position in the landscape. Flooding, if not corrected, dictates choice of crops.

Workability. Emphasize the moisture content at which the soil can be worked or trampled by animals without damaging the structure of the soil.

Natural drainage. Stress how natural drainage can be determined by noting the depth of mottles below the surface. Emphasize how this can be used to determine the need for the removal of excess water or to determine the choice of crops to be grown.

Depth. Depth is of extreme importance in determining the potential for terracing, leveling, diversion, and pond construction. Soil monoliths and field examples are effective teaching aids.

Susceptibility to erosion. Stress why some soils are more susceptible to erosion than others. In teaching about erosion emphasis should be placed on conservation practices.

MECHANICS OF MAP-MAKING

After the farmer has an understanding of how soils differ and how these differences are related to the use and management of the soils, he can then be taught by the paraprofessional how to make an inventory of his soil resources. The latter consists of making a base map and delineating mapping units (soil, slope, erosion) on the base map.

Base map. A drawing board, scale, compass, protractor, pencils, steel pins, notebook, drawing paper, and thumb tacks are all that is needed to make a base map without a plane table, alidade, and chaining equipment (Soil Survey Manual, 1951). All ground measurements should be done by pacing. The average person will count 33 steps in a distance of 99 feet. After selecting the scale and orienting the map with a compass, a series of clockwise or counterclockwise traverses, starting from a known point, are made to establish boundaries, establish corners, and locate physical features by triangulation (Figures 2–5).

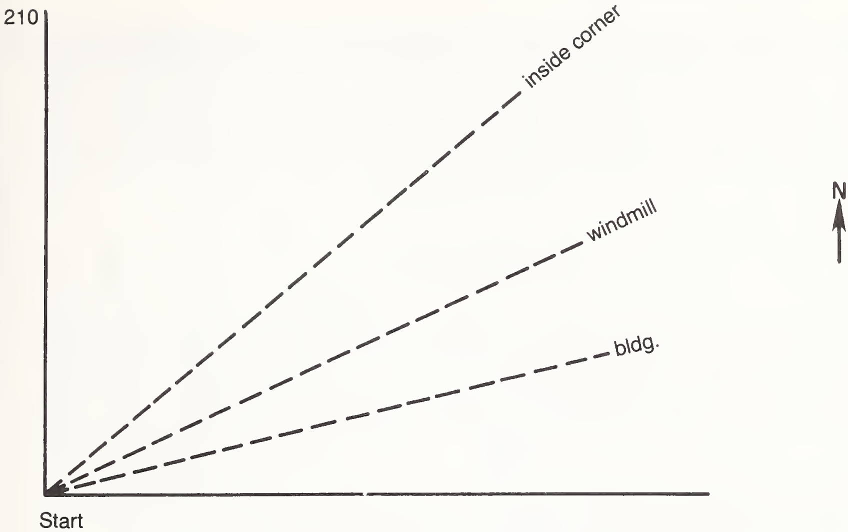


Figure 2. Making a base map.

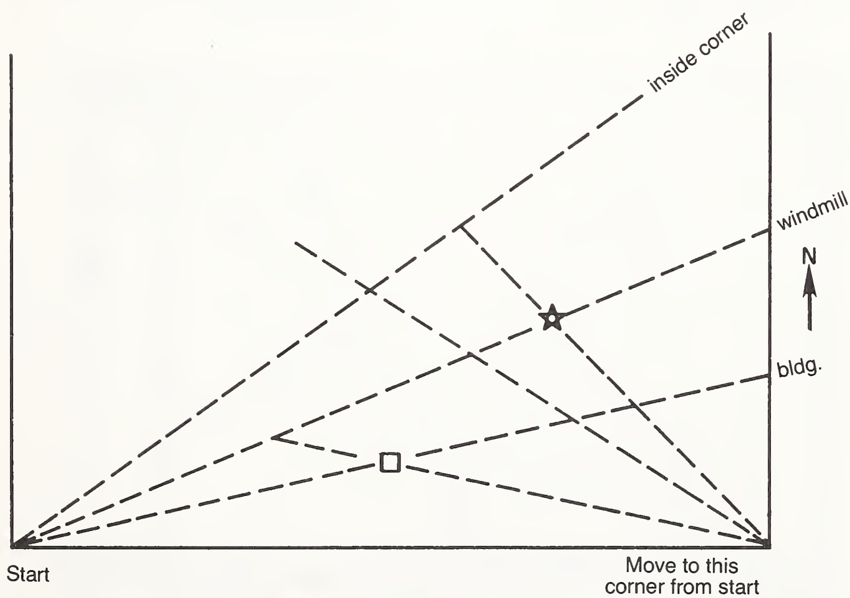


Figure 3. Making a base map.

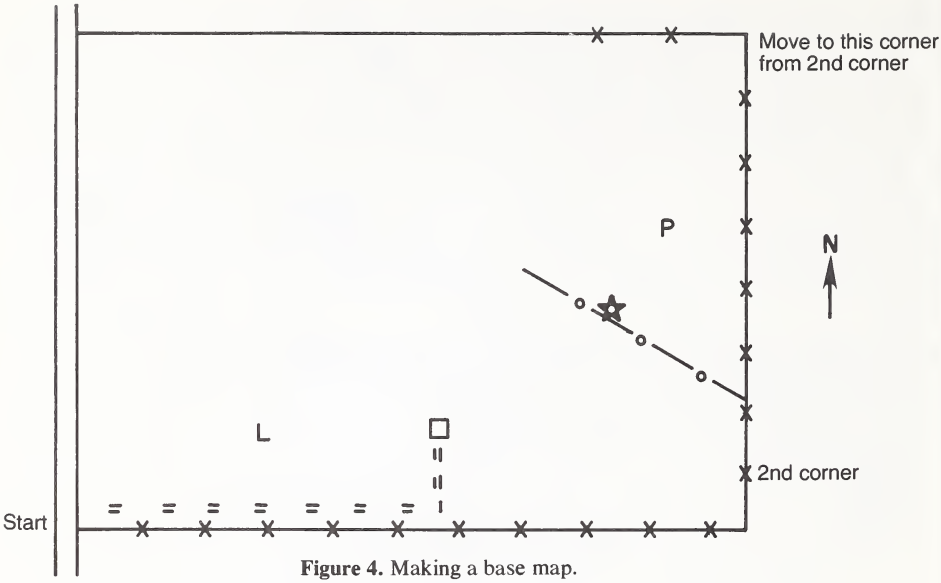


Figure 4. Making a base map.

Scale 4″ = 1 mile

Legend

Boundary fence
Inside fence
Building (or House)
Windmill
Private road
Country road
Cultivated— L
Pastureland— P

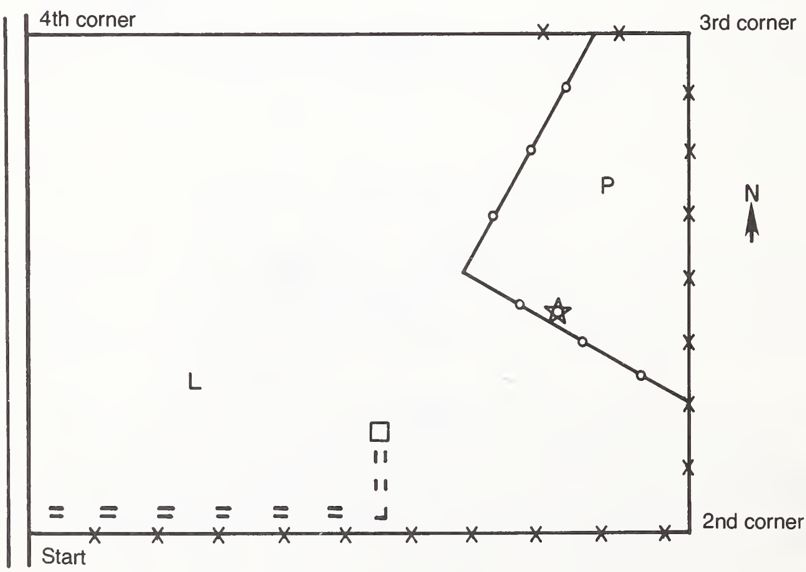


Figure 5. Making a base map.

Delineating mapping units. In his route across the farm to delineate mapping units (soil, slope, erosion) on the base map the surveyor should make periodic stops to note and record useful information. All that is needed for this purpose is a spade or bucket auger, field pH kit, abney hand level or slope finder, soil color chart, pencil, and notebook (Soil Survey Manual, 1951). Figure 6 is an illustration of a survey in progress and Figure 7 is an illustration of a completed map.

DISCUSSION

Once the farmer knows where the different soils on his farm occur and has an understanding of the management problems, he and the para-professional can develop land use plans and soil management systems (Etuk and Collins, 1976; Kirkwood and Dean, 1975; Strickland and Soliman, 1976). Listed below are some alternative crops and alternative practices that should be considered:

1. Crops with deep root systems that will supply large amounts of organic matter to the soil.
2. Crops with fibrous root systems that will supply moderate amounts of organic matter to the soil.
3. Drought-resistant crops.
4. Water-tolerant crops.
5. Salt-tolerant crops.
6. Fast or slow maturing crops.
7. Crops with vigorous root systems.

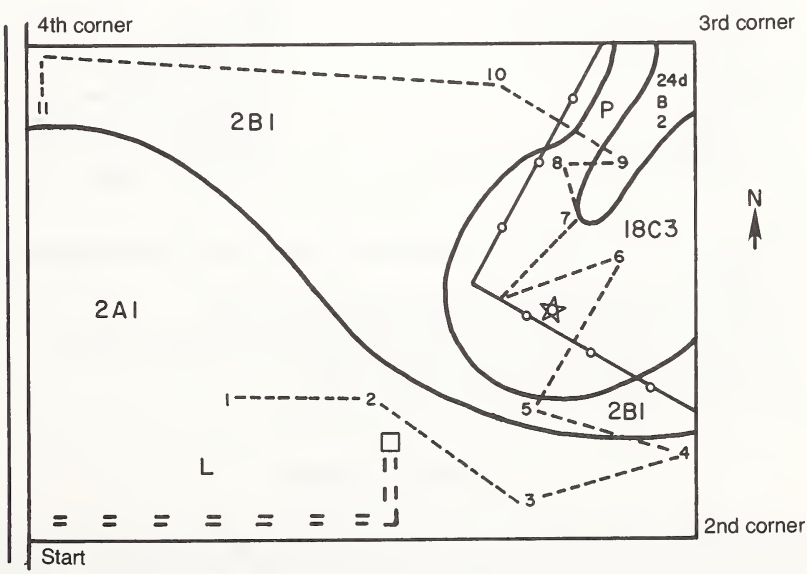


Figure 6. Making a utilitarian soil survey map.

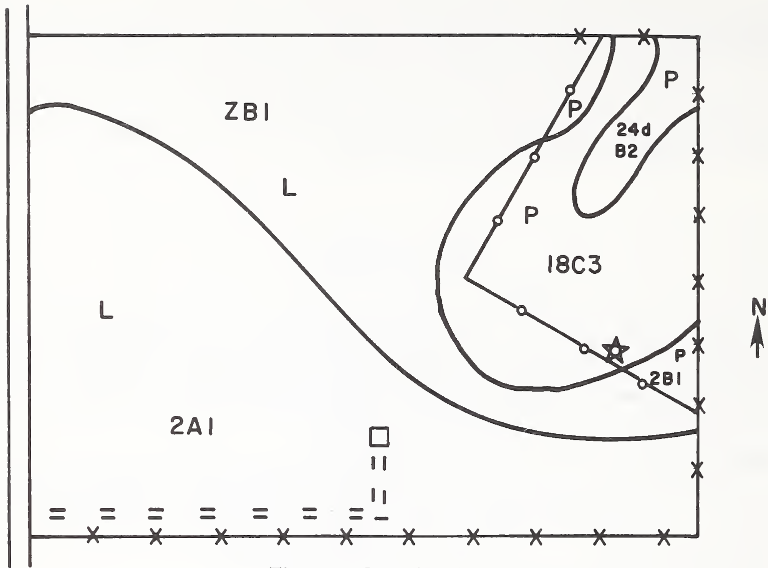


Figure 7. Completed map.

Scale: 1″ = 1320′

Legend

Soil—
2—Deep, fine textured, slowly permeable soil
18—Shallow, fine textured, permeable soil
24—Very shallow, fine textured, gravelly soil

Slope—
A—Nearly level (0 to 1%)
B—Gently sloping (1 to 3%)
C—Sloping (33 to 5%)

Erosion—
1—Slight
2—Moderate
3—Severe (or moderately severe)

Land Use—
Cultivated—L
Pasture—P

Other—
Public Road
Private Road
House
Boundary fence
Inside fence
Soil Boundary
Windmill

8. Crops that will supply large amounts of carbonaceous or nitrogenous organic matter.
9. Practices that will allow for timely tillage of the soil.
10. Practices that will allow for effective application of plant nutrients.
11. Practices that will conserve soil and water.
12. Practices that will not destroy soil structure.

CONCLUSION

The capability of the small farmer to evaluate his soil resources for use and management forms one of the most important bases for agricultural development. Therefore, it is imperative that such a project be launched.

LITERATURE CITED

BIGGS, H. H., and R. L. TINNERMEIER (eds.) 1974. Small farm agricultural development problems. Colorado State University, Fort Collins, CO.

ETUK, L. A., and J. B. COLLINS. 1976. Suggested scheme for reforestation and cropping of abandoned farmlands in Nigeria. Agron. Educ. 5:41–43.

EZUMAH, H. (ed.) 1972. Soils of the tropics: their utilization for a better rural life. College of Agric., Prairie View A & M University, Prairie View, TX.

GUIDE FOR PREPARING SOIL SURVEY LEGENDS. Rev. ed. 1957. USDA/Soil Conservation Service, Berkeley, CA.

HANDBOOK FOR MAKING RESOURCE INVENTORIES. 1963. U.S. Dept. of Interior, Bureau of Indian Affairs, Washington, DC.

KIRKWOOD, J. I., and H. DEAN. 1975. A model for on-site evaluation of soil resources and management problems by the small farmer. College of Agric., Prairie View A & M University, Prairie View, TX.

REACHING THE DEVELOPING WORLD'S SMALL FARMERS. 1974. Special Report, Rockefeller Foundation, New York.

SOIL SURVEY MANUAL. 1951. USDA Agric. Handbook No. 18. U.S. Govt. Printing Office, Washington, DC.

STORIE, R. E. 1964. Handbook of soil evaluation. Associated Student Store, Univ. of California, Berkeley, CA.

STRICKLAND, C. L., and M. A. SOLIMAN. 1976. Non-professional aides in agriculture: an evaluation of a program in cooperative extension education for small-farm families. College of Agric., Prairie View A & M University, Prairie View, TX.

Legend Design for Various Kinds of Soil Surveys

J. D. Rourke

Soil surveys are made to furnish adequate information for land use decision makers. The kinds of decisions these individuals will be making should be, and I maintain must be, made before soil survey commences. The specificity of their needs, and this includes the size of their management units, will determine the field procedures to be used in the soil survey and the scale of the base maps necessary to depict the required detail.

LEGEND DESIGN

Legend design, or the kinds of mapping units, for a given kind of soil survey is determined by: (1) the nature and complexity of the soil pattern, (2) the field procedures used to examine the soils and to plot their boundaries, and (3) the purpose of the soil survey.

The soil classification system defined in *Soil Taxonomy* is the basic reference used in the National Cooperative Soil Survey of the United States to classify soils and interpret soil surveys. It is a multicategoric system with the most specific definitions in the lowest (soil series) category. Each successively higher category is less specifically defined. Classes of the system are used as the references to define and name mapping units of soil surveys. Soil series are the most common reference names used, but classes in other categories are also used.

A mapping unit is a phase of either a named kind of soil, a miscellaneous area, or some combination of the two. The named kind of soil can be at any categoric level in a soil classification system. The purpose of a mapping unit is to provide information significant to use and management. The most specific information can only be provided at the lowest category (soil series) in the classification system. When the purpose of the soil survey is to provide data for operational planning, the information must be specific. When the purpose is to provide data for broad land use planning, the information can be more general in nature or the reference taxa can be named at higher categories in the system.

ORDERS OF SOIL SURVEY

The concept of orders of soil surveys was developed to provide guidelines by which soil surveys made for different uses could be designated with reasonable consistency. The different kinds of soil surveys are designated as follows: 1st Order Soil Survey, 2nd Order Soil Survey, 3rd Order Soil Survey, 4th Order Soil Survey, and 5th Order Soil Survey.

Soil surveys have four attributes: kind and intensity of field procedures used to identify and map the soils, kinds of mapping units (includes soil taxa used to identify the components), scales for field mapping and publication, and minimum size delineations. These attributes can, and often do, vary in degree independently to satisfy in the most reasonable manner the purposes for which a soil survey is made. This purpose will determine the degree of variability among the five attributes; this was used to distinguish the five orders.

In the following discussion emphasis will be placed firstly on the purpose of the soil survey and secondly on the specificity of the information, the kind and intensity of field procedures, kinds of mapping units, minimum size delineations, and map scales required to satisfy this purpose in a reasonable manner.

1ST ORDER SOIL SURVEY

Purpose of soil survey

Provide information for resource conservation planning of highly intensive land uses such as agricultural experimental tracts, high-value commercial agricultural areas, high-density urban areas, and areas planned for intensive development requiring complex, high-cost inputs.

Specificity of needed information. Maximum or near-maximum refinement of soil differences, both categorically and cartographically, that are significant to these very intensive land uses.

Kind and intensity of field procedures. Soils in each delineation are identified by transecting and traversing at closely spaced intervals using direct observation. Mapping unit boundaries are plotted by visual observation throughout this length. Field observations are sufficient to locate and plot areas of dissimilar soil as the minimum size delineation required.

Minimum size delineation. Very intensive land use may require evaluation and decisions about land use and predicting management response for areas of less than 0.6 hectare. The minimum size delineation of dissimilar soils, could, therefore, be 0.6 hectare or smaller.

Mapping scale. The mapping scale must be large enough to accommodate the minimum size delineations of dissimilar soils that are significant to the purpose of the soil survey. As stated in the preceding paragraph, these could be 0.6 hectare or smaller. Mapping scales of less than 1:12,000 have been suggested when the anticipated land use is very intensive.

Kinds of mapping units. Mapping units will be mainly consociations of phases of soil series with narrow ranges of texture, slope, etc. A consociation is a mapping unit in which only one identified taxon, plus allowable inclusion, occurs in each delineation.

Legend design. Examples of these kinds of mapping units are: Alpha silt loam, 0 to 1 percent slopes, and Alpha silt loam, 1 to 2 percent slopes.

2ND ORDER SOIL SURVEY

Purpose of soil survey

Provide information for resource conservation planning for such intensive land uses as high-value general agricultural areas, and urban and industrial areas.

Specificity of needed information. The refinement of the soil information and map detail must be sufficient to determine suitabilities and limitations for all common agricultural and nonagricultural uses and for evaluating management needs.

Kind and intensity of field procedures. Soils in each delineation are identified by transecting and traversing. Mapping unit boundaries are verified at closely spaced intervals and are plotted by direct observation and by some interpretation of remotely sensed data. Field observations are sufficient to locate and plot areas of dissimilar soils as small as the minimum size delineation required.

Minimum size delineation. Resource conservation planning of land use and related management practices where decisions are based on soil resources may be made for areas as small as 0.6 to 4 hectares. The minimum size delineation of dissimilar soils could, therefore, range from 0.6 to 4 hectares.

Mapping scale. The mapping scale must be large enough to accommodate the minimum size delineations of dissimilar soils significant to the purposes of the soil survey. As stated in the preceding paragraph, these could range from 0.6 to 4 hectares. Mapping scales of 1:12,000 to 1:31,680 have been suggested when the anticipated land use is intensive.

Kinds of mapping units. Mapping units are mainly consociations of phases of soil series, and complexes of phases of soil series; some mapping units are undifferentiated groups of soil phases; rarely are mapping units associations of phases of soil series.

A soil complex is a mapping unit in which different kinds of soils (or a soil and a miscellaneous area) occur in a geographic pattern which is so intricate that the individual components cannot be delineated separately at scales of about 1:20,000 or larger.

Undifferentiated groups are mapping units in which two or more kinds of soils occur without regularity of pattern and the individual components can be delineated separately at map scales of about 1:20,000. Each delineation has at least one of the major components and may have all of them. The soils may be either similar or dissimilar but same phase criteria such as steepness of slope, stoniness or rockiness, or flooding for extended periods determines the use and management practice for the purposes of the soil survey. Delineating each individual component separately would, therefore, add unnecessary cartographic detail to the maps, reduce the number of mapping units in the legend, and avoid repetition of the same interpretations in a report.

An association is a mapping unit in which two or more distinctive kinds of soils (or a soil and a kind of miscellaneous area) occur in a repeating geographic pattern. Unlike a complex mapping unit, the individual components could be delineated separately at map scales of about 1:20,000.

Legend design. Examples of these kinds of mapping units are: (1) Consociations of phases of soil series (Alpha silt loam, 0 to 3 percent slopes and Alpha silt loam, 3 to 8 percent slopes); (2) Complexes of phases of soil series (Alpha-Beta silt loams, 0 to 3 percent slopes and Alpha-Rock outcrop complex, 8 to 10 percent slopes); (3) Undifferentiated groups (Alpha and Beta extremely stony soils, 15 to 45 percent slopes); and (4) Associations of phases of soil series (Alpha-Theta association, 8 to 15 percent slopes).

3RD ORDER SOIL SURVEY

Purpose of soil survey
Provide information for (a) resource conservation planning for such extensive land uses as woodland management, wildlife management, and watershed management, and (b) general land use planning, e.g. potential for cropland, pastureland, woodland, urban developments, and rural intensive development.

Specificity of needed information. The information, both categorical and cartographical, need not be as refined as that needed for intensive land use decisions, but it must be sufficient to determine the suitabilities and limitations for general agricultural and nonagricultural uses. General land use planning and resource conservation planning of extensive land uses and related management practices do not require that different kinds of soils, equivalent to the refinement of soil series, be mapped separately.

Kind and intensity of field procedures. The soils in each delineation are identified by transecting and traversing. Mapping unit boundaries are plotted by observation, and by interpretation of remotely sensed data with some observations. Field observations should be frequent enough to locate and plot areas of dissimilar soils that are significant to the purposes of the survey.

Minimum size delineations. The size of the tracts of concern in resource conservation planning for extensive land use and for general land use planning could range from several 10's to many 100's of hectares. Minimum size delineations of dissimilar soils could range from a few 100's to several 100's of hectares.

Mapping scale. Mapping scales ranging from 1:24,000 to 1:250,000 have been suggested for soil surveys intended for resource conservation planning of extensive land uses and for general land use planning. The scale must be large enough, however, to accommodate the minimum size delineations of dissimilar soils deemed necessary for the purpose of the survey.

Kinds of mapping units. Mapping units are usually designed to separate segments of the landscape that because of the location or other physical factors, will be used in the same or similar manner as recognized for the purposes of the survey. If the soils of the survey area are known, the mapping should be associations of phases of soil series. Rarely would these be consociations of phases of soil series and if used, the phases would have a wide range. If the soils are not known, the mapping units could be consociations, associations, and some complexes of phases of families, subgroups, and great groups.

Legend design. Examples of these kinds of mapping units are:

1. Associations of phases of soil series (Alpha-Theta association, 3 to 15 percent slopes, or Alpha-Theta association, undulating to moderately steep);
2. Consociations of phases of:
   a. families (Aquic Hapludalfs, fine-loamy, mixed, mesic, 0 to 3 percent slopes),
   b. subgroups (Aquic Hapludalfs, loamy, mesic, 0 to 3 percent slopes), or
   c. great groups (Hapludalfs, undulating to moderately steep or Fluvaquents, frequently flooded);
3. Complexes of phases of:
   a. great groups (Hapludults-Dystrochrepts complex, undulating to steep), or
   b. suborders (Aquents-Aquults complex, frequently flooded); and
4. Associations of phases of:
   a. great groups (Hapludults-Haplaquents association, nearly level to rolling), or
   b. suborders (Udults-Aquents association, nearly level to rolling).

4TH ORDER SOIL SURVEY

Purpose of soil survey

Provides information for broad land use planning at multi-county, regional, state or provincial level and to identify areas having potential for more intensive development. General accessibility for field soil survey operations may be limited.

Specificity of needed information. The refinement of the information, both categorically and cartographically, can be general in nature. As the land use planning will be broad in nature, the interpretations would be general rather than specific, e.g. for cropland and urban development rather than for maize yields and limitations for on-site sewage disposal.

Kind and intensity of field procedures. The soils of representative landscapes and their pattern of occurrence on these landscapes is determined by transecting. The soils of similar landscapes are verified by some traversing, observations, and by interpretation of remotely sensed data verified by occasional observations. Mapping unit boundaries are plotted by interpretation of remotely sensed data verified by occasional observations.

Minimum size delineations. The size of tracts of concern in broad land use planning could range from 100's to 100,000's of hectares. Minimum size delineations of dissimilar soils could range from several 10's to many 100's of hectares in size.

Mapping scale. Mapping scales ranging from 1:100,000 to 1:300,000 have been suggested for soil surveys intended for broad land use planning. The scale must be large enough, however, to accommodate the minimum size delineations of dissimilar soils deemed necessary for the purposes of the soil survey.

Kinds of mapping units. Mapping units are usually designed to separate landscapes or segments of landscapes that because of location or other physical factors, will be used in the same or similar manner as recognized for the purposes of the survey. Mapping units would rarely be composed of a single kind of soil, even if recognized at the subgroup or great group level. If the soils of the survey are known, the mapping units could be associations of families of soil series. (Families of soil series include all soils having similar physical and chemical properties that affect their responses to use and management and manipulation for use. The responses of comparable phases of all soils in a family are nearly enough the same to meet most needs for practical interpretation of such responses. In order to keep the names of the mapping units as short as possible common family names are used. For example, Alpha family would include all those soils that are classified the same as Alpha soils and whose responses to use and management are similar.) If the soils of the survey area are not known, the mapping units could be associations of phases of subgroups or of great groups.

Legend design. Examples of these kinds of mapping units are: (1) Associations of phases of: (a) families (Alpha-Beta families, undulating), (b) subgroups (Typic Hapludalfs — Fluventic Dystrochrepts association, nearly level to hilly), and (c) great groups (Hapludalfs-Dystrochrepts association, nearly level to hilly).

5TH ORDER SOIL SURVEY

Purpose of soil survey

Very broad general land use planning at multicounty, regional, state, provincial, or national level. Usually, to determine potential for cropland, pastureland, woodland,

urban development, etc., and to identify areas having potential for more intensive development. General accessibility for field soil survey operations is limited.

Specificity of needed information. The refinement of the information, both categorically and cartographically, is general in nature. As the land use planning will be quite broad in nature, the interpretations would be general rather than specific.

Kind and intensity of field procedure. The soils of representative landscapes and their patterns of occurrence on the landscapes are identified and the composition of mapping units determined by mapping selected areas (35 to 50 square kilometers) using the field procedures of 1st or 2nd order soil surveys or alternatively by detailed transects of selected areas. Other areas are mapped by interpretation of remotely sensed data, verified by widely spaced observations.

Minimum size delineations. The size of tracts of concern in very broad land use planning could range from a few million to many millions of hectares. Minimum size delineations of dissimilar soils could range from a few 100's to several 1,000's of hectares in size.

Mapping scale. Mapping scales ranging from 1:250,000 to 1:1,000,000 have been suggested for soil surveys intended for very broad land use planning. The scale must be large enough, however, to accommodate the minimum size delineations of dissimilar soils deemed necessary for the purposes of the soil survey.

Kinds of mapping units. Mapping units are designed to separate landscapes or segments of landscapes that because of location or other physical factors, will be used in the same or similar fashion as recognized for the purposes of the survey. Mapping units would rarely be composed of a single kind of soil, even if recognized at the subgroup or great group level. Mapping units could be associations of phases of subgroups, great groups, suborders, and orders.

Legend design. Examples of these kinds of mapping units are: Associations of phases of: (a) subgroups (Typic Hapludults-Lithic Dystrochrepts association, undulating to steep), (b) great groups (Hapludults-Dystrochrepts association, undulating to steep), (c) suborders (Udults-Ochrepts association, undulating to steep), and (d) orders (Ultisols-Inceptisols associations, undulating to steep). The general purposes of a 5th Order Soil Survey are similar to those of a 4th Order; the difference is mainly in the kind and intensity of field procedures.

SUMMARY

Soil surveys are made to provide data to those individuals who are responsible for making sound land-use decisions that are adequate for their needs. These individuals and the kinds of land-use decisions they will be making are quite varied. The soils data furnished to them should be specific enough for their needs—no more and no less. If the data is less than they need, the decision made can be quite costly in the end. If the data is more than they need, the decision probably cannot be made until the data has been generalized to the point where it meets their needs. When data is more than is required, valuable resources—time, funds, and personnel—have been unwisely used.

The purpose for which a soil survey is being made will determine the kind and intensity of the field procedures necessary to furnish the specificity of the information, both categorically and cartographically, needed for this purpose. Minimum size delineations, map scale, kinds of mapping units, and legend design are, in turn, related to the specificity of the information needed.

Soil Survey: Its Quality and Effectiveness

R. Webster

THE PURPOSE OF INFORMATION

Soil survey is a general procedure whereby information is obtained about the soil of areas of land. The information can be about particular attributes of the soil, for example, the presence or absence of calcium carbonate, boulders or rock near the surface, soil horizons and their sequences. It can consist of measured values of soil properties such as depth, strength, permeability, salinity, cation exchange capacity, or nitrogen content. Or the survey might record only the kinds of soil present. The information can be gained by visual inspection or measurement in the field, laboratory analysis, or microscopic examination.

The purpose of soil survey is sometimes to aid understanding of current land use or soil formation, or to serve as the basis of tax assessment. In the developing countries it is more often done because some change in land use is envisaged: e.g. land settlement, agricultural development, road or airfield construction. The soil properties recorded will relate to the activities envisaged, and the people making the survey may well record their judgments on the suitability or otherwise of soil for such activities. We may regard judgments of this sort as information if we like, but we must distinguish them clearly from inferences about the soil at places not actually visited.

Soil is continuous, but most information about soil, certainly that concerning its intrinsic properties, derives from observations at discrete places, often no more than a few centimetres or few tens of centimetres across, more or less widely separated from one another. We cannot record what the soil is like everywhere. Yet those who commission soil surveys often want to know just that. They want to be able to infer, or predict in a spatial sense, the nature of the soil at many unvisited or unrecorded places from relatively few observations made elsewhere. So, although the essential business of soil survey is the collection of information, the way in which the information is obtained, organized, and used is a substantial and almost ever-present problem. Much of the mystique of soil survey concerns this problem; so do many of the misunderstandings of soil survey and the arguments that follow from them. The fact is that the precise nature of the problem varies from country to country, and often from district to district within a country. It depends on the purpose for which information is wanted, the size of area involved, and the staff and other resources available for survey. There is therefore no universal solution, but many more or less different ones tailored to particular circumstances.

SOIL MAPS

Mapping is usually a part of survey procedure. Indeed it has become so much a part of soil survey procedure that soil survey and soil mapping are thought to be the same thing by many people. As we shall see, they are not. Maps are nevertheless important visual aids, and provided we recognize the distinction between survey and map, we shall find it convenient to think in terms of the maps that are or could be produced.

The type of map produced in most soil surveys is familiar enough. It shows the land surface divided into parcels, within any one of which the soil is considered to be of the same kind or of a few kinds that can be listed and described. Parcels of a similar nature are grouped into classes, which constitute the legend of the map—the soil classification for that map. The parcels on the map are disjoint but contiguous, and the whole of an area surveyed falls into one or another parcel. Coverage is complete. Maps that partition an area in this way are known generally as *choropleth* maps. We can take the term into our vocabulary of soil science, as we shall need it to distinguish between these and other kinds of soil maps.

In many instances the choropleth map represents the surveyor's attempt to show the extent of certain classes of soil profile. But as we now know it is not very successful. We can expect no more than about 60 percent of the soil in any one mapping unit to belong to the class of profile it purports to show. Such maps do not display data. Instead their main function is to serve as indexes to data. On output from a soil survey a choropleth map shows the limits, as soil boundaries, within which data can be safely used for prediction.

Similar maps are often made at an early stage in a survey. The boundaries are drawn on evidence of land form, changes in vegetation or land use, appearance on air photographs, and prior knowledge of the geology. The fundamental assumption is the same, namely, that the soil within any one class is sufficiently similar or definable to allow useful prediction. But its function is to allow economy of sampling. It can be used to ensure that every important extent of soil is adequately covered while avoiding undue replication on any one kind. On completion of the survey the map may be published with little or no alteration, again serving as an index to the available data. And both this and maps of the former type can serve as sampling frameworks for later investigators gathering their own information.

Choropleth maps are quite the most familiar soil maps, but they are not the only ones. We should be aware of at least two other types.

Point symbol maps

In these the condition of the soil is shown by symbols placed at points corresponding to the positions where the observations were made. The symbolism can be more or less complex. It can show simply presence or absence of some character; it can show by means of a grey or colour scale several levels of a variable; it can combine two or more characters. But in all cases point symbol maps are displays of actual data. Any inference about the soil at intermediate points, by interpolation for example, is made by the user of the map, not by the map maker. Perhaps the leading proponent of point symbol soil maps is C. C. Rudeforth in Great Britain. He has developed several techniques for displaying sample data in this way, and prepared numerous maps. See for example Rudeforth (1975), Rudeforth and Bradley (1972), and Rudeforth and Webster (1973).

Isarithm or contour maps

A continuous variable, e.g. thickness of soil or hydraulic conductivity, can be mapped by means of isarithms, lines of equal value. The data values are assumed to lie on a continuous surface of varying shape, and to be sufficiently close that they are spatially dependent, i.e., near points are more likely to be similar than distant points. Mapping consists of constructing the surface from the data and then displaying the result. Such maps can look very like topographic contour maps. Indeed, they are often called "contour" maps, and the procedure by which they are made is often termed "contouring." The terms should be used with caution, however, because there is an important difference between topographic contour lines and isometric lines representing a soil variable. The former are drawn to join points of known equal value; the latter, even where they pass through observed values, join points of inferred equal value. It is, of course, quite impossible to identify actual isometric lines for any property of the soil.

Isarithm maps are sometimes used in detailed planning work, and are likely to become more familiar now that they can be made automatically from sample data.

Neither point symbol nor isarithm maps are as closely integrated with data collection as are choropleth maps. They are essentially adjuncts. Once data have been collected, and nowadays stored in a computer, maps can be made from them as and when required.

Finally in this section, we should recognize that for some purposes maps are not needed at all. A planner, for example, might ask how much soil there is in an area suitable for some enterprise. He could be answered by a surveyor's first mapping soil types in the conventional way and then measuring each parcel of soil judged to be suitable. However, since the planner is not asking where all the suitable soil is the answer could be provided at much less cost by a statistically sound sampling procedure, from which the proportion of the total area, and hence how much land is suitable, can be estimated.

PURPOSE OF SURVEY

As above, soil survey is not an end in itself: it is done for a purpose. In some instances the purpose is very specific, for example the identification of areas in which zinc or chromium is so concentrated in the soil that it is likely to poison plants growing there, or the design of foundations for a new airfield. Such surveys are special purpose surveys. In other instances survey is carried out to provide an inventory of the soil as a resource. The use made of the survey depends on what is found. These surveys are general purpose surveys, and usually involve recording many properties of the soil.

SURVEY INTENSITY AND APPLICATIONS

The actual soil information obtained by survey derives from the sampling points. The sampling intensity can vary from very dense, say more than 100 points per ha for foundation design, to less than one point per km^2 in rapid surveys of large areas. Sampling intensity is often linked to the scale of map that can be constructed and published with reasonable confidence. This is very roughly five observations per cm^2 of map. The connection is necessarily rough because, for choropleth mapping at least,

it takes no account of the judicious use of other information. Some quite satisfactory maps are based on a much less dense sampling than 5 points/cm^2 of map. Allowance must also be made for the user who will tolerate imprecise soil information but must have a large scale map that shows detail of other sorts. For example, in laying gas supply pipes it is more important to have accurate cadastral information than it is to know precisely where the soil changes from one type to another (unless that change is unusually abrupt).

With these qualifications in mind we can divide the range of survey intensity into a few groups. The following, based on FAO practice, will serve.

Descriptive term	*Scale range*
Intensive	1:10,000 to 1:2,500 or more
Detailed	1:25,000 to 1:10,000
Semi-detailed	1:100,000 to 1:25,000
Reconnaissance	1:500,000 to 1:100,000

The denominators of the division points are of course convenient round numbers. Some organizations find it equally convenient to publish their soil maps at these same scales, making it difficult for us to decide which class of survey intensity would be most appropriate for them. This is not serious; it simply shows that the precise division points are quite arbitrary.

Intensive surveys

These are required to plan enterprises on small areas (a few ha to a few hundred ha) in detail, for example, buildings, irrigation layouts, and intensive farm and plantation management, especially in the context of problem solving. Information from vegetation, land form, and air photographs does not usually lead to economy of effort, and almost all information must be obtained by intensive sampling. That in turn is expensive and is only justified for costly enterprises.

Intensive surveys are almost always special purpose ones, and properties are measured only if they have a direct bearing on the purpose. For example, a fruit grower planting an orchard might wish to know the depth and drainage characters of the soil; a construction engineer would want measurements of bearing strength, Atterberg limits and shrinkage, before designing foundations. The data are usually well suited for isarithmic mapping, and this is often done.

Detailed surveys

These too are carried out for specific projects though over somewhat larger areas, for example, agricultural development including irrigation works. More soil properties might be of concern here than in the previous group. In many instances information derives largely from sampling, but in others use may be made of surface features to distinguish soil types. No one procedure dominates, and the group represents a gradation between the intensive and semi-detailed groups.

Semi-detailed survey

Soil surveys in this group are made for a variety of purposes. Some are special purposes, in which particular soil properties are of interest, for example, geochemical survey. Others have specific ends that depend on several soil properties. Examples

include location of new settlement and assessment of potential for agricultural development. The systematic surveys carried out in Western Europe and North America also fall into this group. They are general purpose, principally resource inventories, with choropleth maps as integral parts of the procedure. In most instances the classes represented, soil series and the like, are homogeneous types; that is, each can be regarded as uniform for many practical purposes, and any local variation is small enough to be ignored. Some mapping units are defined as mixtures, complexes, etc., but these are the exception rather than the rule.

Reconnaissance survey

The surveys in this group are almost always of large areas—national territories or large regions within them. The term *reconnaissance* is applied because the surveys are often carried out rapidly or with few staff or with limited access or some combination of these, and information is a good deal sparser than either those making the survey or their clients would wish. Those who make reconnaissance surveys often do so on the understanding that the survey is a preliminary to more detailed work, if resources allow, of the whole area, or of those parts that seem the most suitable for some specific purpose. Surveys at this scale are carried out to provide resource inventories of large areas. For strategic planning the main aim is to obtain sufficient, and reasonably uniform, coverage of information for the whole country or region. Though the scale of survey brings it into this group it is not properly reconnaissance.

The small-scale maps from such surveys are almost always choropleth maps. But the kinds of mapping units differ greatly from map to map, and in some instances from unit to unit on the one map. Some maps purport to show individual classes of soil, usually at some coarse level of classification, e.g. great soil groups or some such. Others more honestly show dominant soil types. Yet others show soil associations—groups of more or less different types of soil that occur, and usually recur, in association with one another in the areas bounded.

An extension of this is the land system map. Land systems as such were first mapped in the North of Australia to help assess the agricultural and pastoral potential of that country (Christian and Stewart, 1953). A land system is akin to a soil association in that it is a pattern of recurring elements of land, but differs from a soil association by embracing more than just soil; land form, surface geology, water regime, and often natural vegetation are additional attributes of it. Its advantages, even from a soil surveyor's point of view, are that both it and its component parts, which we can call *land facets,* are much more readily recognized and mapped than are soil types or associations. Land systems can be distinguished on air photographs with confidence. Land system survey is now a valuable tool for remote areas and has been carried out to advantage in many countries for both agricultural and engineering purposes.

In reconnaissance surveys soil data are not only sparse but also do not usually relate to any one whole mapping unit. In fact, it is not immediately obvious how generalization or prediction of any kind can be made from the data, since the parcel in which any data point lies can contain areas of very different soil. Data from a point can sensibly be extrapolated only to other parts of the same type of soil, say soil series or land facet, that is within a class than can be treated as uniform. A land system or soil association map is not itself a sufficient index or guide. There must also be means for identifying the type of soil or land facet at both sampling points and at other points for which predictions are wanted. These must be provided in an explanatory document accom-

panying the map. The map will then tell the user which mapping unit is relevant, and the description of the mapping unit will enable him to decide which soil or land type occurs at any point of interest. It is a distinct two-stage process. The British Royal Engineers contributed substantially to this aspect of land survey in the 1960s, and the results are reviewed by Beckett et al. (1972).

RELIABILITY OF SURVEY

Records made by novices in the field and data from ill-equipped laboratories and poorly maintained instruments cannot be relied on. Information obtained by experienced staff using sound equipment will be reliable, in the sense that it faithfully describes the condition of the soil at the sampling points. But to be useful or effective such data must also represent the soil of some area well and so allow worthwhile prediction and generalization.

To be properly representative sampling points should be chosen without bias. This is best done in such a way that every point in the area to be represented has an equal, or at least known, chance of being chosen. In detailed and intensive surveys this can be achieved fairly easily. In semi-detailed and reconnaissance surveys it is less easy or uneconomical, and is very unusual in practice. Instead representative sites are chosen intuitively by surveyors. The practice depends on having surveyors with experience and sound judgment; otherwise the risk of bias, which is always present, becomes serious.

UTILITY OF DATA

Sample data may be required for either generalization about the soil of areas or for prediction or both.

Generalization

Taking generalization first, it is clearly helpful for a farmer to know the average phosphate content of his soil, since from this information he can judge how much phosphate fertilizer to buy. Similarly a mining company might wish to know how much aluminum the soil contains; that information would enable the company to judge whether to invest capital to strip the area for bauxite. In these instances the mean value is of interest. Its estimate can be improved simply by increased sampling. The precision is proportionate to the square root of the sample size.

Prediction

Prediction is different. A plantation manager might wish to know the depth of soil at many places on his plantation; a military tactician will be concerned with the bearing strength of the soil along a continuous tract of country. If they lack other information they might use the mean values of depth or strength as predictors. But the confidence that they place in the prediction depends on the variance of the property concerned. The more variable the soil is the more in error prediction is likely to be. Increased sampling does not of itself reduce this error.

Classification

There are two ways of improving prediction from sample data. The first, and most familiar to soil surveyors, is to link the data to a soil classification (or choropleth map) of the area. Prediction for any point is then based on data from the soil class (mapping unit) to which the point belongs. The variance within the class is likely to be less than in the area as a whole, and hence the confidence interval for prediction should be narrower. The prospect is attractive: reality is less so. Our experience suggests that the variance of a soil property within classes at series level is unlikely to be less than half that in the larger landscape or survey area. For some properties in some areas a particular classification may bring about no reduction in variance, and in one instance that was examined exhaustively general purpose classification brought about no worthwhile decrease in the variance of any property of interest (Webster and Butler, 1976). The user of a soil classification should expect modest improvements in prediction rather than spectacular ones, and should always be prepared for the situation where a soil classification is unprofitable. The method also demands a reasonable sample for each class recognized, otherwise the class means themselves will be subject to substantial error. One of the tasks of survey is to judge the best compromise between creating many classes to diminish within-class variance and increasing the sampling effort needed to describe those classes adequately.

Interpolation

The other and less familiar method of improving prediction is numerical interpolation, in which the value of a variable is based on the values at previously sampled points and on their distance away. Now with machines to take on the heavy computing involved there is renewed interest in interpolation.

A number of methods have been proposed for interpolation. Each is an attempt to be intuitively reasonable, to make the best of machine resources (program, data, and intermediate results must fit into the computer and jobs run to completion in the time allotted), and to work empirically.

One method, known as *kriging* (Matheron, 1965) in earth sciences, is optimal. It provides unbiased estimates of the true values. The estimation variances are minimal, and it is in this sense that the method is best. Further, the variances can themselves be estimated, so that kriging is a proper statistical estimation procedure. The method has recently been introduced into soil survey (Burgess and Webster, 1980a, 1980b; Hajrasuliha et al., 1980), and it promises to be applicable in many situations.

For any kind of interpolation to be worthwhile the sample points on which it is based must be closer than the limit or range of spatial dependence. The range, if it exists, can be determined by determining the correlogram (Webster and Cuanalo, 1975) or more usually in earth science its complementary function, the semi-variogram (Matheron, loc. cit.). In general the sample spacing should be no more than half the range, and with this proviso the more intense the sample survey the better will be the interpolation. Kriging takes into account the specific form of the semi-variogram up to the range, and from it the sample spacing needed to achieve any particular precision can be determined (McBratney et al., 1981; McBratney and Webster, 1981).

With these ideas in mind we can see why different procedures are needed to make use of information at different levels of intensity. In intensive and detailed surveys a sampling interval of 20 m to 100 m is usually well within the range of spatial dependence, which might be an order of magnitude larger. Interpolation then makes the best

use of the data. If there are obvious sharp changes these can be taken into account. At the semi-detailed level the interval at which observations are made and the range of spatial dependence are of the same order of magnitude, and are often about the same. Interpolation is unprofitable, but simple classification is an economic alternative. At the reconnaissance level simple classification is also unprofitable, and we need two-stage indexing for our information. The effectiveness of a two-stage reconnaissance map therefore depends on (1) the homogeneity, or within-class variance, of the soil types of land facets listed, and (2) the quality of the identification aids to the soil types and facets, in addition to accurate delineation of the mapping units.

The above represent the limiting conditions for interpolation and classification. We should also recognize that there are practical limits to the refinement that we can hope to achieve. As above, roughly half the total variance of a soil physical property in an area of say 100 km^2 can be accounted for by a soil series or land facet classification. Of the remainder we should expect to find again about half present within 100 m^2, or even 1 m^2. We cannot generalize quite so readily for chemical properties. Some are apparently unrelated to any formal or obvious soil classification; others are related. But all still show very considerable variation within a 10 m distance. This variation will remain present as noise in most sampling schemes or classification, since in practice we cannot sample closely enough nor create enough mapping classes and delineate them to take account of it.

CLASS PURITY

The foregoing discussion on reliability and utility of survey data is presented in terms of continuous variables—quantities like zinc content, bearing strength, lime requirement—that are or can be measured. In many surveys the characters of interest are attributes. If the attribute is strictly binary (e.g. present or absent) then it can be treated as above, though it might be better to apply Shannon's information statistics.

One line of study in particular needs mention. It is that concerning the purity of soil mapping units. In this approach it is assumed that soil mapping attempts to partition an area into parcels such that each parcel contains one and only one class of soil profile. The classes of profile are disjoint, and may be defined prior to survey. Soil being what it is the attempt is never wholly successful, and the mapping units always contain some proportion of soil other than the classes they were intended to bound. They are always more or less impure, and the several studies carried to assess impurity show it to be anything from 25 to 65 per cent. The results are depressing if taken seriously.

However, I believe that purity of this kind is largely irrelevant. For practical purposes the map provides the definitive classification to which useful data are indexed by virtue of their location. The soil profile class is not information that the user wants. The information he does want is about individual soil properties or about the suitability of soil for particular purposes. Provided the survey produces a map showing homogeneous areas, each mapping unit should be substantially pure with respect to its suitability. If there is any doubt about this for a specific purpose then the suitability of the soil should be assessed at a number of places on the map to establish the facts. A few results from this kind of investigation are available and show that the mapping units can be treated as uniform, just as the surveyors intended. The following example from Beckett et al. (1972) is an illustration, and enables us to end on an optimistic note. The Oxford district of England, covering some 2,400 km^2, had been mapped into land

facets (homogeneous classes of land) by a combination of air photo analysis and field work. Twenty-nine test sites were then chosen at random on six of the facets and visited by engineers who assessed the suitability of the sites for the construction of airfields. The results, given in Table 1, show a very strong association between the land classification and suitability for airfield construction.

Table 1. Contingency table showing the number of test sites in the Oxford district in each facet and airfield suitability class.

	Land facet					
Airfield suitability class in rank order	13	1	10	3	4	5
1	5					
2		5				
3			4	1		
4					3	2
5				3	3	3

SUMMARY

Soil survey is a procedure for obtaining information about the soil of areas, from which to generalize and predict. Soil mapping is usually part of the procedure. Choropleth maps (area partitions) are the commonest type of soil map, and show the limits within which point data can safely be extrapolated. With automation isarithm maps are a reasonable alternative. They display statistical surfaces interpolated from point information.

The utility of a survey depends on competent staff recording relevant soil properties at enough representative sites. The utility of the data obtained is more or less enhanced by interpolation in intensive surveys, by map classification in semi-detailed surveys, and by a combination of classification and descriptive guides to class identification in reconnaissance work. There are nevertheless practical limits to the extent to which these enhance prediction. There is always substantial short-range variation unaccounted for.

Choropleth maps of soil can be used to predict suitability classes of land for various purposes, and are generally successful. The estimation of purity with respect to a formal classification is unprofitable, and unnecessary for this purpose.

LITERATURE CITED

BECKETT, P. H. T., R. WEBSTER, G. M. MCNEIL, and C. W. MITCHELL. 1972. Terrain evaluation by means of a data bank. Geogr. J. 138:430–456.

BURGESS, T. M., and R. WEBSTER. 1980a. Optimal interpolation and isarithmic mapping of soil properties. I. The semi-variogram and punctual kriging. J. Soil Sci. 31:315–331.

BURGESS, T. M., and R. WEBSTER. 1980b. Optimal interpolation and isarithmic mapping of soil properties. II. Block kriging. J. Soil Sci. 31:333–342.

CHRISTIAN, C. S., and G. A. STEWART. 1953. General report on a survey of the Katherine-Darwin region, 1946. Land Research Series No. 1. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

HAJRASULIHA, S., N. BANIABASSI, J. METTHEY, and D. R. NIELSEN. 1980. Spatial variability of soil sampling for salinity studies in south-west Iran. Irrig. Sci. 1:197–208.

MCBRATNEY, A. B., R. WEBSTER, and T. M. BURGESS. 1981. The design of optimal sampling schemes for local estimation and mapping of regionalized variables. I. Theory and method. Computers and Geosciences 7. (In press.)

MCBRATNEY, A. B., and R. WEBSTER. 1981. The design of optimal sampling schemes for local estimation and mapping of regionalized variables. II. Program and examples. Computers and Geosciences 7. (In press.)

MATHERON, G. 1965. Les variables régionalisées et leur estimation. Masson, Paris.

RUDEFORTH, C. C. 1975. Storing and processing data for soil and land use capability surveys. J. Soil Sci. 26:155–168.

RUDEFORTH, C. C., and R. I. BRADLEY. 1972. Soils, land classification and land use of West and Central Pembrokeshire. Special Survey No. 6. Soil Survey of England & Wales, Harpenden.

RUDEFORTH, C. C., and R. WEBSTER. 1973. Indexing and displaying of soil survey data by means of feature-cards and Boolean maps. Geoderma 9:229–248.

WEBSTER, R., and B. E. BUTLER. 1976. Soil classification and survey studies at Ginninderra. Aust. J. Soil Res. 14:1–24.

WEBSTER, R., and H. E. CUANALO DE LA C. 1975. Soil transect correlograms of north Oxfordshire and their interpretation. J. Soil Sci. 26:176–194.

PART ONE

SOIL RESOURCE INVENTORIES

Section II.
Soil Survey Methodology: Techniques

The Use of Airphoto Interpretation and Remote Sensing in Soil Resources Inventories with Special Reference to Less-Developed Countries

Ta Liang and Warren R. Philipson

This paper reviews the use of remote sensing[1] methods in soil resources inventories, and discusses the potentials and limitations of their future use in light of current technological developments.

INTRODUCTION

The use of airphotos in soil resources inventories began with their serving as base maps in the field, in the early 1930s, when airphotos first became available. Gradually, more and more techniques were developed to extract soil information from airphotos. By the 1950s there were many mapping programs which depended heavily on airphotos as the major source of soil information. Comparisons of results of airphoto interpretation and field methods were attempted. While the accuracy of photo interpretation depends largely on the scale of photos, level of mapping categories, and competency of the interpreter, it has been also generally recognized that the use of airphotos in soil resources inventories has been more successful than its use in detailed soil surveys. Such soil resources applications have expanded rapidly and extensively during the past twenty years.

Since the mid-1960s, the use of color and color infrared photos has become more common. In addition, more and more spectral data, both in digital and image format, have been acquired. Since the early 1970s, satellite-derived data have been routinely available at increasing frequencies. With the multitude of data, semi-automation and automation in interpretation and presentation are not only desirable but necessary under certain circumstances. Now seems an opportune time to assess the significance of these developments and how best to make use of them effectively.

[1]Airphoto interpretation is a part of remote sensing, although it often is separated in the literature.

Why airphotos were used

Historically, airphotos were used because they provide an impartial (or undisturbed) visual record of the land, and in 3-D, when acquired and viewed stereoscopically. Existing photos are generally available in most parts of the world; there are relatively few regions that do not have some type of airphoto coverage, and many have repeated coverages. Thus, they provide an inexpensive and excellent source of soil information.

Basic approach of photo interpretation

A major cornerstone in photo interpretation is the evaluation of landform units. Through stereoscopic study of airphotos, the topographic (slope), drainage, soil erosion, gray or color tone, vegetation and land use characteristics can be assessed; relevant landforms and pertinent soil, rock, and water features can be determined; field study plans can be formulated and subsequent field data interpretation greatly facilitated.

POTENTIALS AND LIMITATIONS OF PHOTO INTERPRETATION

As photo interpretation has been developed primarily with the physiographic approach, it is therefore strong in revealing physical characteristics of soil and rock, including such items as texture, moisture, permeability, and cemented beds, in the profile. For instance, the assessment of landslide and ground water potential, the estimation of depth of soil over bedrock, and the location of construction materials by photo interpretation are well documented (Colwell, 1960 and Reeves, 1975). These are useful to the engineering and geology disciplines as well as to soil science. Hence, photo interpretation has been highly successful if we consider "soil resources" in a broad sense.

However, many limitations should be noted. In addition to the limitation of scale, the quality of airphotos is not only affected by photographic processing but unavoidably by season and time of photography and the associated atmospheric, foliage and ground cover, and moisture conditions. Furthermore, the potential of extracting chemical and biological data from photos is low; such information, if obtainable at all, usually is derived through observation of subtle photo patterns by highly competent interpreters.

It should also be noted that an airphoto is a record of ground conditions at only one point in time. Further, interpreters should be especially aware of the possible influence of an environment, natural or manmade, that he might not be familiar with. These, and the open-ended nature of photo interpretation, are nonetheless limitations that would apply as well to all field investigations.

SPECIAL CONSIDERATIONS IN LDCs

Before leaving the discussion on conventional photography, several factors pertinent to LDC conditions are relevant.

Large regions, few maps

In many LDCs, airphotos served most effectively because there were few alternatives. In recent years, in Australia and many other Commonwealth countries, large regions

were mapped into land systems, subsystems, or similar units based on common physiographic, geologic, soil, and vegetative characteristics. Medium scale (1:40,000) airphotos have been used as sources of basic information. Supported by ground checks, maps produced even at such general levels could serve many planning and development purposes. More detailed follow-up studies could be accomplished with larger scale photos.

Tropical soils

Most of the LDCs are located in the tropical or subtropical regions of the world. There, items such as plinthite, ironstone, termite mounds, black clays (Vertisols), and coral-related materials are significant in agriculture as well as in engineering and economic development. Airphoto patterns of these and others have been reported in the literature (Liang, 1965).

Tropical vegetation

In the arid and semi-acrid tropics, airphotos are most effective because of the cloud-free atmosphere and the fact that there is little vegetative cover to mask the soil and moisture conditions. The opposite is true in the humid to wet tropics. Some of the wettest parts of the world, such as those in Panama, Colombia, Brazil, Philippines, and Indonesia, experience such extreme levels of cloud cover that radar images had to be used.

In many areas, although flying airphotos are possible, heavy forests have hindered ground interpretation. Two opposite approaches have been taken. One is to fly high-level photography (at 1:60,000 scale or smaller) so as to get a large perspective and hopefully to enable the recognition of landforms in spite of the "superficial" forest cover. The other approach is to fly low-level photography (at 1:10,000 scale or larger) to get a close view of the structure and pattern of the forest and then to deduce the ground conditions, considering the prevailing temperature and moisture environment (Holdridge et al., 1971). It is apparent that the former is a simpler solution; the latter requires more specialized personnel, and at present is still very much in the developmental stages (except for some of the well-established species-soil relationships such as mangroves-swamp).

Identification of crops by use of airphotos has been reported (Philipson and Liang, 1975). Future development along this direction would allow the assessment of soil resources through the interpretation of crop status and management practice. At present, photo patterns of major crops are established. More work is needed for refinements in some lesser crops, mixed crops, and small farms, and in the correlation of crops and soil resources parameters.

PHOTOGRAPHIC TECHNIQUES

Sequential and planned photography

Because one set of existing photography often was not taken at the optimal time to depict foliage, moisture, and other ground conditions, and since one-time photography does not register the short-term and long-term changing conditions, it is often desirable to use sequential photography. This would include photos taken periodically in the past, as well as planned photography in the future.

Color and color infrared photography

Since the early 1960s, color and color infrared photos have been more commonly available and used in soil resource projects. Many comparisons of color with panchromatic (black-and-white) airphotos have been made (Colwell, 1960 and Reeves, 1975). The consensus has been that color and color infrared generally add information and that color infrared particularly brings out certain subtle vegetative characteristics[2], and both expedite the interpretation process. The drawback has been the higher cost and demanding facility in photographic reproduction. To counter some of the problems, the use of both color and black-and-white prints from color negatives has been one compromise practice.

The basic consideration might be reduced to whether the incremental information obtained from colors justifies the additional cost and effort. This would vary under differing situations. When the interpretation depends largely on topography (slope), drainage and seepage, panchromatic photography is highly effective and often sufficient; where land use, crops and vegetation have to be interpreted, color photos undoubtedly are superior. One also should consider whether bare soil would be exposed and whether direct observation of soil on photos is possible and essential.

Spectral data—images/tapes

Since the mid 1960s, applications of spectral data (identified as "tones" in the conventional panchromatic photo interpretation) in soil resources studies have developed rapidly. With multispectral photographic systems or scanners, ground information is recorded in image or digital form. This information can then be displayed or enhanced and manipulated, in accordance with the spectral characteristics of the various component parts of the ground. This approach has enabled the separation of moist soils from other dark soils on the photos, for instance, and more refined differentiations require experiments to cope with local or regional parameters. The major consideration here is whether the spectral characteristics of surface material are significant. Sometimes this "tone" characteristic is crucial for separating meaningful soil units; other times it could be irrelevant. An extensive experiment in southwestern Pennsylvania in the early 1970s proved that this approach yields remarkable results with bare soils but fails hopelessly when obscured by ground covers (Reeves, 1975).

Automation and semi-automation

A logical development with multispectral data is automation. The practice varies from simple color display and automatic area integration to training computers in differentiating target areas and mapping ground units automatically. Some sort of man-machine interaction is (or should be) required in most procedures . The potentials and limitations here are similar to those discussed under 'spectral data,' but with automation, their order of magnitude is multiplied and the task may easily extend to large area coverages. Compared to traditional interpretation methods, the major bottlenecks facing automation today are: (1) lack of topographic (slope) input and (2) lack of the required sophistication for expressing the reflectance pattern (tonal pattern or texture). Both have been major elements in traditional photo interpretation. Until breakthroughs are made in these (and efforts are being made by some groups), progress for automation in soil resources interpretation would be slow.

[2]While this is generally true for crops and many natural vegetated areas, a major experiment in tropical forests has demonstrated that under humid tropic conditions, where growth is luxurious, color is often superior to color infrared (Holdridge et al., 1971).

Thermal infrared, passive microwave, radar

Only brief comments about these sensors are included to complete our "shopping list". Thermal infrared, not to be confused with photographic infrared, measures temperature-related radiation. Thus, the incremental information it can provide is surface temperature. It would differentiate soil, rock, vegetation types, and moisture regimes only when there are significant temperature or emissivity differences. These differing types often are already observable in photos, which normally provide much better resolution and less distortion than thermal infrared images.

Passive microwave and radar operate in much longer electromagnetic wavelengths. These have the advantage of all-weather ability, but are greatly limited by the low resolution of available data. Further, the current cost of mobilizing and operating such sensing systems is high and may not be justifiable in most LDCs for soil investigations alone. The advantages, however, of a multiple channel approach should not be overlooked. With further development, such prospects as limited penetration of ground by long wave radar channels seem attractive.

SATELLITE DATA

Since 1972, the series of Earth Resources Technology Satellites (Landsats 1 and 2) have provided four-spectral band data over most of the earth, at 18-day cycles. This is of major importance to all who are concerned with resources inventories (Williams and Carter, 1976).

The major advantages of the Landsat images are:

1. Synoptic views of large areas (185×185 kilometers per image) of nearly all parts of the world.
2. Sequential coverage (every 18 days).
3. Four spectral bands (individually recorded; subject to practically endless manipulation).
4. Available and at nominal costs to any user.

The limitations are:

1. Resolution (now about 80 meters).
2. Lack of 3-D view.

Because of the limiting resolution, the use of Landsat data in detailed soil resources inventories is out of the question. However, in many areas for which general maps are unavailable or poorly done, the Landsat images provide excellent base maps. Then, making full use of the four spectral bands, one may perform visual interpretation through the use of a color additive viewer or similar equipment, or digital analysis with tapes; major physiographic or landform units, various geologic features, and land use patterns can be differentiated.

The outlook for future satellite-derived data appears to be bright. Several countries are planning to install data-receiving facilities in addition to those currently being operated in and by Canada, Brazil, and Italy. Furthermore, Landsat C, which is scheduled to be launched in 1978, is to add a thermal-band sensor; others in the series to follow are being planned to include more spectral bands with better resolution. Advanced sensing devices are also planned for the forthcoming Seasat. Generally, one

could look forward to a resolution of 30 meters or better in the near future. Supplementing these, data derived from weather satellites are being used in hydrologic (in addition to weather) studies on a regional basis. These images provide high frequency sequential data, though with gross resolution (0.5 to 4 kilometers).

EQUIPMENT

The lowly pocket stereoscope is still the most convenient and frequently used piece of equipment for many basic photo interpretation tasks. Depending on the level of sophistication and type and quality of data, more elaborate and high-priced equipment (including stereoscopes, color additive viewer, density slicer, densitometer, and a number of rectifying and enhancing equipment for semi-automation and automation) might be used, not to mention the associated extensive computer systems. Each organization should consider its own needs and acquire the basic equipment, instead of rushing to buy some very costly items that may not necessarily provide much additional information. Such items may also become obsolete in a relatively short time. It is highly commendable that many are suggesting, even in this country, some well-equipped regional centers be established to meet the needs of users in a region. LDCs would be prudent to take this road to conserve resources.

SUMMARY

Photo interpretation/remote sensing plays a major role in data collection for soil resources inventories. This is particularly significant in LDCs where there is a general lack of existing maps or information.

Current techniques in panchromatic airphoto interpretation depend heavily on the landform approach, yielding information that is strong in physical aspects of the land but weak in chemical and biological aspects. This approach, however, may continue for some time, with possibly some refinements in interpreting soil, weathering, crops, and forests in the tropics, thus providing improved inputs to the soil resources inventory.

Color, color infrared photos, and other spectral data provide incremental information over panchromatic photos about soil color, vegetation, and land use. Thermal infrared, passive microwave, and radar — each has its respective merits, but their resolution, and the limited availability and high cost of the latter two, have greatly hindered their practical uses.

The recent availability of space data (Landsat and others) provides some new and inexpensive sources that one should watch closely, particularly considering the scheduled improvement in resolution and spectral coverage for future satellites.

In summary, for soil resources inventory projects, the multitude of possible photos and images now available as tools is really a challenge as well as an opportunity for the user. One should assess his regional or national requirements, consider the constraints of each tool and the personnel, equipment, and facilities involved, and formulate the best approach for his program.

LITERATURE CITED

Colwell, R. N. (ed.) 1960. Manual of photographic interpretation. Am. Soc. of Photogrammetry, Falls Church, VA.

Holdridge, L. R., W. D. Grenke, W. H. Hatheway, T. Liang, and J. A. Tosi, Jr. 1971. Forest environments in tropical life zones. A pilot study. Pergamon Press, Oxford.

Liang, T. 1965. Airphoto interpretation of engineering soil in tropical environments. p. 531–535. *In* Proc. Third Symposium on Remote Sensing of Environment. Environmental Research Institute of Michigan, Ann Arbor, MI.

Philipson, W. R., and T. Liang. 1975. Airphoto analysis in the tropics: crop identification. p. 1079–1092. *In* Proc. Tenth Int. Symposium on Remote Sensing of Environment. Environmental Research Inst. of Michigan, Ann Arbor, MI.

Reeves, R. G. (ed.) 1975. Manual of remote sensing. Am. Soc. of Photogrammetry, Falls Church, VA.

Williams, R. S., Jr., and W. D. Carter. 1976. ERTS-1, a new window on our planet. U. S. Geological Survey Professional Paper 929. U. S. Govt. Printing Office, Washington, DC 20402.

Soil Analysis for Soil Surveys

H. Eswaran

Although a useful and necessary component of soil survey reports is profile description and soil analysis, many reports tend to omit this information. In some cases no analyses were performed due to lack of facilities or the analyses were not complete at time of publication of the report.

As the soil report is the only means that the soil surveyor has to communicate his findings to the users, it is necessary that he define his units in the most unambiguous terms. Soil analyses aid him to do this and the quality of the report is greatly enhanced if all his mapping units are described in morphological, geographical, and physico-chemical terms.

There are few guidelines to assist the soil surveyor in deciding the number of pedons to be described and analyzed, the type of analysis to be performed, and perhaps also the use of this information in his report. This contribution attempts to evaluate some of these questions and provide some suggestions.

WHY SOIL ANALYSES

Soil analysis in soil survey reports are included to define in numerical terms the physico-chemical properties of the major soils of the area. The morphological descriptions and physico-chemical properties are employed to classify the soil. As the analyzed profiles are considered to be representative samples of the area, the measured properties are extrapolated to generalize the behavior or response of the soil to specific uses.

The several different uses of soil analyses are:

In relation to the soil survey reports

1. To characterize numerically the properties of some or all of the mapping units. If some data are available at the commencement of the survey or during the early part of the survey, they enable the surveyor to calibrate himself. At the end of the survey they enable him to establish relationships between soil properties and other morphological and landscape parameters.
2. To aid in the correct classification of the soil and enable others to place the soil in other taxonomies.
3. To serve as a basis for more detailed evaluation of the soils; preliminary information on nutrient, physical, or other limitations needed for developing a capability classification may be extrapolated from such analyses.

In relation to developing a resource inventory of the region or country

1. For correlation purposes, it is necessary to build up a soil data bank. Creating new series or grouping old ones is then done on a rationale basis.
2. To use in other areas where no data are available but physiographic conditions indicate possibility of similar soils.
3. To develop soil property interrelationships which enable one to predict a property which is difficult or inconvenient to measure.

In relation to evaluating limiting properties

1. To determine levels of elements which may be toxic or deficient or levels of soil conditions which may be limiting to use of the soil. As the surveyor is frequently called upon to assess the potentials of the soils, he needs these limits.
2. To delineate soils which require various levels of investment for their economic utilization.

In relation to their genetic properties

1. To aid in an understanding of their composition and formation. These investigations are generally the most comprehensive but in some cases tend to deal with the unique or the obscure.
2. To evaluate the changes induced by management practices and thereby determine optimal types of management.

TYPES OF ANALYSES

The objectives of the survey determine the types of analyses to be performed. Soil analyses are grouped into classes (Table 1) to reflect these objectives.

Class Ia analyses are those which are necessary to classify the soil in most taxonomies and form the minimum type of analyses that should accompany profile descriptions. In some cases Ib or Ic analyses are necessary but an estimate of some of the latter may be made from Ia analyses. Every soil survey laboratory must be equipped to perform most or all of Class I analyses.

Class II are performed for special surveys. The number of samples is usually large and samples may be taken at specific depth intervals in the soil. Auger samples are generally employed and samples from unit areas may be bulked to reduce sampling error. Single property maps are based on such data.

Class III analyses generally do not appear in soil survey reports of LDCs as these are considered "academic." These studies are useful to develop concepts and build up classification systems.

NUMBER OF PROFILES OR HORIZONS TO BE ANALYZED

The number of profiles to be analyzed is a function of the scale of the map and the objectives of the survey. Table 2 attempts to determine the basis for selection of profiles for characterization and the types of analyses to be performed. Profiles are selected to show not only the basic characteristics but also the range in properties.

Table 1. Types of analyses in relation to objectives.

Class I **Analyses required by *Soil Taxonomy***	**Class II** **Analyses performed for specific objectives or problems. (Generally performed on site, or on undisturbed samples or on auger samples.)**	**Class III** **Analyses performed for genetic studies.**
a. General analyses required on all horizons on all profiles 1. Particle size distribution 2. Organic carbon, nitrogen 3. Cation exchange capacity (NH_4OAc, pH 7) 4. Exchangeable bases: Ca, Mg, Na, K 5. pH in H_2O and 1*N* KC1 (1:1) 6. 1*N* KC1-extractable A1 7. $BaC1_2$—triethanolamine (pH 8.2) H^+ 8. CBD-extractable Fe_2O_3	a. Physical and engineering properties 1. Infiltration 2. Permeability 3. Available water 4. Bearing capacity 5. Other engineering properties	1. Extraction or dissolution techniques 2. Mineralogical 3. Micromorphological 4. Equilibration
b. Analyses required on a few selected profiles to test specific requirements of *Taxonomy* *Analysis* — *Examples in Taxonomy where required* 1. Bulk density — Andepts, 'Hum-' suborders and GG 2. pH in 1*N* NaF — Andepts, Spodosols 3. 15 bar H_2O — Inceptisols, Alfisols, Ultisols, Oxisols 4. CEC by 1*N* NH_4C1 — Oxisols 5. COLE value — Vertisols, Vertic SG 6. Conductivity — Aridisols, some families 7. $CaCO_3$, $CaSO_4$ — Aridisols, Mollisols	b. Chemical properties on soil 1. Salinity, alkalinity 2. pH fresh, dry, or with oxidisers 3. Toxic substances (Arsenic, Boron, Nickel, Chromium, Sulphides, Iron) 4. Fertility-related properties employing different kinds of extractants 5. Eh	(The above are performed in addition to some or all of Class I and II analyses.)

Table 1. Types of analyses in relation to objectives.

Class I Analyses required by *Soil Taxonomy*		**Class II** Analyses performed for specific objectives or problems. (Generally performed on site, or on undisturbed samples or on auger samples.)	**Class III** Analyses performed for genetic studies.
c. Analyses required on a few selected horizons to test specific requirements of *Taxonomy*		c. Chemical properties on water at site or incoming water	
1. P_2O_5	Anthropic horizon	1. Suspended solids	
2. Pyrophosphate-extractable Fe, A1	Spodic horizon	2. Dissolved salts (electric, SAR)	
3. Fine/course clay ratio	Argillic horizon	3. Toxic substances (Boron, Magnesium, Lithium, $C1^-$, SO_4^{--}, CO_3^{--}, HCO_3^-)	
4. Mineralogy of clay	Argillic horizon	4. pH	
5. Mineralogy of fine sand	Soil families		

Most profiles are sampled to a depth of 2 m unless particular soil conditions or objectives require shallower or deeper samples. The normal procedure is to sample morpho-genetic horizons and when a horizon is thicker than 25 cm, one sample is taken for each 25 cm.

CONSIDERATIONS ON COST OF SOIL ANALYSES

Many a soil surveyor hesitates to send in soil samples for analysis due to the costs involved, particularly if done by a commercial lab. This is a limiting factor with respect to the number and type of analyses.

Costs of soil analysis must be considered in relation to:

1. cost of the whole soil survey, and
2. cost of development of the area.

Cost of the soil survey is indicated on a ha basis and in many LDCs, this does not exceed 10 or 20 cents per ha (for a map of 1:63,000). No estimate of cost per ha of soil analysis is available but this is not expected to be more than 10% of the cost of the soil survey. However, both the costs are a small fraction of the total developmental costs of the area.

For example, in Malaysia it costs about $500 per ha to bring an area into rubber or oil-palm. The benefits accrued due to the recommendation of the soil survey far outweigh the cost of soil survey and soil analyses. Consequently, cost of soil analyses should not limit the number or types of analyses within the limits suggested in Table 2. Obviously a survey can use analytical data obtained in earlier work.

QUALITY OF SOIL ANALYSES

Quality control is very important and there are several ways to attain this:

1. Inter-laboratory cross-checks,
2. Sample duplication, and
3. Statistical approach.

(1) and (2) are followed by some labs. Quality control deals with not only the laboratory but also the surveyor. When the same soil series is identified in different parts of the country, it is necessary to verify the similarity of their physico-chemical properties. The coefficient of variation (CV) is a good parameter to evaluate this. The acceptable CV is determined to a large extent by the property in question. Beckett et al. (1971) have provided some levels.

SOIL ANALYSES IN LDCs

Constraints to good analyses in LDCs

Many soil data from LDCs tend to be less reliable for several reasons:

1. Lack of qualified lab personnel. Training of lab personnel in analytical methods should be an equally important contribution of aid programs. FAO personnel in

Table 2. Selection of profiles for analyses and types of analyses to perform.

Kinds of Soil Survey	Scale Publ. Map	Selection of Profiles for Analyses	Types of Analyses
Class A	< 1:7,920	Minimum one per taxonomic unit plus other samples to show limiting or specific characteristics	All or part of Class I or II
Class B	7,920-24,000	Minimum one per dominant soil series or equivalent	All or part of Class I or II
Class C	24,000-62,500	Dominant soil families or equivalent	Class Ia with or without others
Class D	62,500-250,000	Dominant subgroups or equivalent	Class Ia, Class III with or without others
Class E	250,000-500,000	Dominant great groups or equivalent	"
Class F	>500,000	Dominant soil orders or equivalent	"

Thailand, faced with this problem, have organized in-service training programs and provided a manual which gives all details.

2. Equipment. Two situations generally prevail. If there was a technical aid project, the labs are equipped well, but as lab personnel are not trained to maintain equipment and spare parts are difficult to get, the equipment is no longer used after the departure of the experts. In the absence of a foreign project either the labs are bare or stocked with the most fancy equipment. However, a survey by FAO of more than 225 labs in LDCs (Brogan et al., 1965) indicated that most of the labs were well equipped to perform the general analyses required for soil surveys.

3. Chemicals. This is the most expensive item in LDCs as most chemicals are imported. Even if money is available, one may have to wait six months to a year to obtain chemicals.

Minimum equipment needed for a soil survey laboratory

A soil survey laboratory is perhaps one of the cheapest laboratories to establish and maintain. The instruments indicated below will suffice for most soil survey require-

ments. A more comprehensive list of equipment needed for soil survey laboratories is given by Golden et al. (1966).

1. Atomic absorption spectrophotometer
2. UV—visible spectrophotometer
3. pH meters (at least two)
4. Conductivity meters
5. Electrical balances (two to four)
6. Hot plate with magnetic stirrers (ten)
7. Water-bath (two)
8. Ovens (two)
9. Furnaces (two)
10. Glassware

Optional:

1. Flame photometer
2. Teflon bombs or platina and nickel crucibles
3. Centrifuges

If funds are available the following are useful:

1. X-ray diffraction units
2. DTA-TGA thermoanalyses
3. C, H, N analyzer
4. Equipment for making thin-sections

Types of analyses

Table 1 lists most of the analyses employed and procedures are given in the manual on laboratory techniques (Soil Conservation Service, 1972). There is a trend in many countries to adopt most of these methods, perhaps because they have stood the test of time. However, there are local modifications which one has to be aware of. The danger comes when the lab uses the name of an established method but a totally different procedure. For example, free iron is usually determined by the CBD method. There are reports where free iron is determined by: (a) Deb procedure, (b) a 6 *N* HCl extract, or (c) Ammonium oxalate—oxalic acid extraction in the dark, in the light, or with UV light. Each of these methods gives a different value. There is perhaps a need for adopting conventions regarding names of methods.

An assessment of published soil survey reports

In Table 3, some information is given on a few soil survey reports of LDCs (randomly picked out, one from each country). A few have all class Ia analyses; some include other data, and a few have none. In some, profile descriptions are so vague that the analytical data become less meaningful. In one, the profile that was described is not the same as the one analyzed. In the same report the modal profile was sampled in another locality. In many reports, the profile description and analytical data are addendums to the report; reference to these are absent in the text.

The number of profiles analyzed bears no relationship to the mapping or taxonomic units. The number of horizons sampled is clearly a function of the training of the surveyor.

Table 3. Types of analyses in soil reports of LDCs.

Areas of Survey and Reference	Map Scale	Area of Survey (km^2)	No. Pedons Analysed[a]	Average Sample Pedon	Texture		pH			Exchange Properties					B.S. %	H^+ 8.2	KC1 A1	C	N	B.D.	Free Fe_2O_3	Cond. mm-hos/cm	$CaCO_3$
					Int.	USDA	H_2O	KC1	Other	CEC	Ca	Mg	Na	K									
Bangladesh (1)	126,000	3000	23 (5)	4	X		X				X	X	X	X				X	X				
Thailand (2)	100,000	4100	19 (23)	5		X	X	X		X	X	X	X	X	X	X		X	X			X	X
Malaysia (3)	126,000	800	8 (23)	5	X			X		X	X	X	X	X	X			X	X				
Philippines (4)	200,000	13430	0/36																				
Sierra Leone (5)	50,000	2590	14/16	3	X		X		X	X	X	X	X	X				X	X				
Lesotho (6)	250,000	30344	(20)	3	X	X	X		X	X	X	X	X	X	X	X		X	X				X
Usutu Basin, Swaziland (7)	50,000	910	?	?	X		X	X	X	X	X	X	X	X	X			X	X			X	X
Songhor Area, Kenya (8)	50,000	526	(41)	7		X	X			X								X	X				
Antsohihy, Madagascar (9)	20,000	10000	(30)	3	X		X			X	X	X	X	X	X			X	X				X

[a]Numerals in brackets give the number of mapping units in legend.

CONCLUSION

Despite the importance of soil analyses, in general the least attention is directed to them. There is a lack of appreciation of soil analyses and many soil surveyors of LDCs do not seem to be informed on the interpretation that could be made.

It will be useful and perhaps a valuable contribution if aid projects are directed to:

1. Training of laboratory personnel in analytical techniques.
2. Training of soil surveyors, especially soil survey assistants, on soil analyses and interpretation of data.

LITERATURE CITED

Beckett, P. H. T., and R. Webster. 1971. Soil variability: a review. Soils Fert. 34:1–15.

Brogen, J. C., P. Lemos, and R. E. Carlyle. 1965. A survey of soils laboratories in sixty-four FAO member countries. FAO Soils Bull. No. 2. FAO, Rome.

Golden, J. D., P. Lemos, R. E. Carlyle, and F. C. R. Freitas. 1966. Guide on general and specialized equipment for soils laboratories. FAO Soils Bull. No. 3. FAO, Rome.

Soil Conservation Service. 1967. Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Investigations Report No. 1. U.S. Govt. Printing Office, Washington, DC 20402.

SOIL SURVEY REPORTS EMPLOYED TO DERIVE TABLE 3

Carroll, D. M., and C. L. Bascomb. 1967. Notes on the soils of Lesotho. Tech. Bull. 1, Land Res. Div., Div. of Overseas Surv. Tolworth, Surrey, England. (2 sheets, scale 1:250,000).

Department of Agriculture, Kenya. 1960. Soil survey of the Songhor area, Kenya. Govt. Printer, Nairobe, Kenya. (2 sheets, scale 1:50,000).

Murdoch, G., and J. P. Andrisse. 1964. A soil and irrigability survey of the lower Usutu Basin (South) in the Swaziland lowveld. H. M. Stationery Off., London. (3 sheets, scale 1:50,000).

Paramananthan, S., and S. W. Soo. 1968. Reconnaissance soil survey of Perlis. Malayan Soil Survey Report No. 3/1968. Soil Science Div., Min. of Agric. & Cooperatives, Kuala Lumpur, West Malaysia. (2 sheets, scale 1:126,720).

Scholten, J. J., and W. Boonyawat. 1971. Detailed reconnaissance soil survey of the northern part of Chiang Rai Province. Report SSR-86. Dept. of Land Development, Bangkok, Thailand. (1 sheet, scale 1:250,000; 5 sheets, scale 1:100,000).

Simon, A. 1975. Soil survey of Samar Provinces, Philippines. Soil Rep. 42. Bureau of Soils, Dept. of Agric. & Natural Resources. Govt. Printing Office, Manila. (1 sheet, scale 1:200,000).

Soil Survey Report of Netrokona Subdivision in the District of Mymensingh. 1960. Dept. of Agric. Bull. No. 5. East Pakistan Govt. Press, Dacca. (1 sheet, scale 1:126,720).

STOBBS, A. R. 1963. The soils and geography of the Boliland region of Sierra Leone. Govt. Sierra Leone. (4 sheets, scale 1:50,000).

VIEILLEFON, J. 1963. Notice sur les cartes pedologiques de reconnaissance au 1/200,000^{e}. Feuille No. 8. Antsohihy. L'Institute de Recherche Scientifique de Madagascar, Tananarive—Tsimbazaza. (1 sheet, scale 1:200,000).

Soil Properties and the Use of the U.S. *Soil Taxonomy* in Northern and Western Africa

Pierre Ph. Antoine

The following remarks stem out of personal observations made in Northern Africa but can generally apply to other semi-arid regions of lesser developed countries.

There are two major ways to improve from the "outside" the knowledge on land resources of a given country. first, one can respond to a direct request made by officials of a government and agree to work on "urgent" problems involving survey work and land evaluation. This approach is often strictly technical and generally avoids or minimizes any type of interaction with local agronomists in order to maximize short-term efficiency (which in most cases can be read: profit).

On the other hand, one can also try to design long-term programs which involve cooperative efforts and training of local scientists. This second approach is not strictly technical but also implies some social interaction. It generally requires more effort from the individuals involved.

TECHNICAL ASPECT OF USING THE *SOIL TAXONOMY*

To many biased American pedologists, the best type of map is a comprehensive map which includes "all" soils properties, including physical and chemical characteristics and relationships between various members of soil sequences.

This type of map, however, which can be called a *soils map* "sensu stricto" is generally of little use to scientists in other fields of specialization involved in land resource evaluation, planning work, or fertility recommendations, since both the average pedestrian and the general agronomist often confuse soils units and archaeological findings.

If the above assumption is correct, a soils map therefore can simply be considered as a tool. It is the best tool—and the cheapest on a long-term basis—to be used to derive other types of maps (capacities, constraints, cultivation potential ...) because, by definition, it contains all the information necessary to draw those maps.

However, unless unlimited time, money, and expertise are provided—and this is never the case in LDCs—one has often to settle for reconnaissance or semi-detailed maps which do not fully provide the entire set of information requested by various land users.

Advantages

As far as the soils community in the U. S. is concerned, a great deal of money and effort has been spent on designing a soil classification scheme based primarily on morphological characteristics of soils. This is based upon the biased but respectable assumption that soil is mostly a support for plant growth. Among other traits of originality, the U. S. *Soil Taxonomy* differs from many other classification schemes in its obvious attempt to quantify every soil parameter and to express most soil properties by means of numbers and averages (thickness of horizons, percentages of organic matter, P_2O_5, etc.).

The U.S. *Soil Taxonomy* is also a system of classification which introduced the concept of soil *regimes* and *cycles,* i.e., moisture and temperature. This introduction obviously constitutes a step forward in soil studies since it provides a link between cultivation cycles, fertility constraints, and that support for plant growth called soil. It also reminds the scientist that soil is in constant evolution and must be studied in a dynamic perspective. As a side remark, we might regret that the *Taxonomy* did not pursue its efforts further and ignored a whole series of other regimes present in soils: chemical and physical cycles involving pH, levels of available nutrients during the year, osmotic and physical pressures, and so on.

In terms of survey work in North and West Africa, where lack of sufficient moisture during certain periods of the year is perhaps the most severe constraint to crop production, the characterization of soil moisture regimes is certainly essential to build a good knowledge of soils and understand their behavior. The prediction of a soil moisture regime is a difficult exercise and the relationship between rainfall and soil moisture regime is very general and does not always fit the goals of crop production.

In the region of Midelt for example, at an elevation of about 1600 m one has observed within a distance of less than 300 m, a succession of at least three moisture regimes: aridic, xeric, and udic. In terms of land use and crop production, those different characteristics result in sizable differences.

Disadvantages

However, unfortunately, the U. S. *Soil Taxonomy* offers some serious disadvantages. As in most countries of Africa, Asia, and South America, available soil moisture data are very scarce in Northern and Western Africa. Moreover, the definition of soil regimes involves not only one set of observations, but rather measurements scattered throughout the year and over long periods of time (e.g., averages over a ten-year period). This, of course, makes the problem even more complicated.

Consequently, the use of the *Soil Taxonomy* in a map legend implies too many assumptions, guesses, and erroneous interpretations. Even though the adjectives "tentative" or "temporary" can be used in the legend, having to "update" a mapping unit by changing the names of taxa, sometimes at the highest level of classification (e.g., going from an Aridisol to an Inceptisol), is a painful exercise.

Suggestions

Remarks similar to those made for moisture regimes can also apply to other soil properties or characteristics. Some of these may also affect directly the classification of soils (e.g., the evolution of soil structure during the year, which frequently must be taken into consideration when characterizing Mollisols in Mediterranean regions, and which requires observations at times which are not best suited for other soil observa-

tions). Some other properties may influence less directly the classification of soils, at least at the highest levels of classification, but are of great importance for fertility recommendations, and therefore should be clearly integrated into a system which aims at linking soil properties and crop production. For example, little is known yet concerning chemical properties of soils of subtropical regions as they relate to fertility; rates of mineralization of organic matter, yearly cycles of available K^+ and nitrate levels in soils, constraints linked with the absence or overabundance of minor elements (toxicity) in some Alfisols, are still generally ignored.

In conclusion, unless the users of the *Soil Taxonomy* working abroad decide to abandon their sophisticated tool and to adopt other and sometimes more "simple" (easier to use) soil classification schemes, it is the feeling of this writer that the knowledge of the properties listed above must be greatly improved if *Soil Taxonomy* is to be used successfully. In this respect, among all properties essential for characterization in semi-arid regions, a high priority must be given to the characterization of moisture regimes. To achieve that goal, a few options are available among others:

1. The soil scientist may improve his knowledge of vegetation species which usually provide excellent indications concerning moisture parameters, and try to relate physiological properties of plants to the soils environment. Too often, the pedologist is more a good geomorphologist or a mineralogist than a botanist.
2. The scientist may also design computer models which relate climatic data to soil moisture regimes for all kinds of soils environments and soils characteristics: different slopes, aspects, surface, temperature, vegetative cover, texture, succession of horizons. This involves the establishment of field plots and bench mark programs in many different locations and requires a good dose of enthusiasm and confidence.

   Improving the knowledge of moisture regimes, not to mention the other soil properties upon which the *Taxonomy* insists, may be a costly proposition. However, because of the critical importance of water for crop production in semi-arid regions, there is much to gain in that direction and the results should be worth the investment.

USE OF MAPS, INTERACTION WITH LOCAL SCIENTISTS, AND TRAINING OF SOIL SURVEY EXPERTS

Proving that the *Soil Taxonomy* is useful and eventually may be used in LDCs constitutes only one of the goals of the taxonomist, and a really minor one.

Long term objectives of overseas work often imply the creation in each country of an organization capable of handling local agricultural problems. Too often, it has been observed that technical masterpieces which are not generated from within a host government have no impact upon the future and only benefit "academia" or the more developed countries. This is true of many types of activities in land resource evaluation, soil conservation work, plant breeding programs, etc. Incredible amounts of money have often been invested for the making of elaborate reports which are comfortably installed inside drawers and remain locked for years and years. Too many soil maps have been considered as sleeping beauties by scientists of various LDCs.

To have a significant impact, a technical report or a technical recommendation must always carry some credibility. One of the best ways to gain that credibility is to involve

local scientists in every study (whenever possible) and invest time and efforts in the training of future experts who can, hopefully, share an identical technical point of view.

The preceding remarks are of much importance to the users and the "missionaries" of the *Soil Taxonomy*. Northern and Western African countries have a limited number of pedologists. For the most part, these pedologists have been trained in France and most of their survey work has been accomplished by means of references to the French Classification. Using the *Soil Taxonomy*, therefore, becomes a very risky venture if local agronomists do not see the need for it. Caution and patience must be exercised.

Eventually, the basic question: "Why use the *Soil Taxonomy* in such conditions?" will arise and the answer is not easy. Specific recommendations must be adapted to local conditions. It is a fact that soil scientists are often reluctant to switch from one system of classification to another. Taxonomists are not an exception to that rule. "Chauvinistic" attitudes are common and may be the major reason why soil symposiums are generally so colorful.

The history of development of soil classifications in European countries and in North America and this common "chauvinistic" attitude of mind can lead to a major danger which must be avoided by all means: the birth and development of new local soil classifications based on the introduction of local terms. All efforts must be made to encourage scientists of developing nations to integrate themselves into an already existing classification scheme and to participate directly in its development.

From experience in North Africa, the following remarks can be made. We have been somewhat successful in doing soil survey work at a large scale in pilot areas and in training Moroccan soil scientists in the French and American systems of classification at the same time. To do so, whenever possible, we have used identical quantified parameters to define taxa in the two systems, without departing from existing rules. (The major permissible effort in that direction deals mostly with the selection of horizon thickness and depth of solum. For this, depths listed in the *Taxonomy* have been selected to characterize different categories of soils.) A legend has been written in terms of both classifications, the series and phase column being shared by both systems (Table 1).

The major advantage of such an effort is to allow scientists trained in different countries to use this type of survey work and to keep the door of the future open to those people who will, some day, make decisions concerning the choice of soil classifications in their own country.

GENERAL CONCLUSIONS AND SUMMARY

The successful use of the U.S. *Soil Taxonomy* in Northern and Western Africa is technically feasible, but must still involve massive efforts in collecting quantitative information before full use of the *Taxonomy* can be made.

In addition, the possibility of using the *Taxonomy* does not imply, by definition, its acceptance in various countries. Attempts must be made at training African soil scientists in the *Taxonomy* before trying to "force" upon them the acceptance of the system. Whenever possible, it is also highly desirable to relate and bring together both the French and American systems of soil classification.

Table 1

Classification Francaise C.P.S.—1967: Classe S/Classes	Groupe S/Groupes	Familles	Symboles des séries et phases	Définition des séries et phases intégrant la U.S. *Soil Taxonomy*, 1973
Sols minéraux bruts non climatiques	Sols d'érosion, lithosols	Sur matériaux d'âge primaire et sur tertiaire	A (indifférencié)	Affleurements géologiques ou Xérorthent lithique, squelettique, thermique, pentes fortes: (>15%)
Sols peu évolués non climatiques	Sols d'érosion, lithiques	Sur chistes	Bf	Xérochrept lithique, thermique, texture fine, squelettique; pente forte supérieure à 15%
			Bg	Xérochrept lithique, thermique, texture moyenne peu profond; pente forte supérieure à 15%
	Sols d'apport colluvial et alluvial modal	Sur apports colluviaux et alluviaux	Bc	Xérofluvent typique, thermique, limon sableux, profond, pente faible
			Bd	Xérofluvent typique, thermique, sableux profond pente faible
	Sols d'apport colluvial et alluvial hydromorphes	Sur apports colluviaux et alluviaux	Be	Xérofluvent aquique, thermique, limon sableux, profond, pente faible
Sols calcimagnésiques	Sols bruns calcaires à encroûtement calcaire	Sur marne calcaire	Eb_1	Xérochrept calcixérollique; thermique, texture fine, peu profond, pente forte (>15%), couverture sableuse en surface
			Ed_{12}	Xérochrept calcixérollique, thermique, texture fine, squelettique, (<20 cm), pente forte supérieure à 15%, mince couverture sableuse avec galets (4 à 5 cm et 15 à 20%)
			Ef_1	Xérochrept calcixérollique, thermique, texture moyenne, moyennement profond, pente forte (>15%), mince couverture sableuse avec galets (4 à 5 cm et 15 à 20%)
		Sur gres calcaire	Eg	Xérochrept calcixérollique, thermique, texture moyenne, peu profond, pente forte (>15%).
			Ef	Xérochrept calcixérollique, thermique, à texture fine, squelettique, pente forte (>15%)

Evaluation of Rice Lands in Mid-Country Kandy District, Sri Lanka

S. Somasiri, R. L. Tinsley, C. R. Panabokke and F. R. Moorman

Rice is the preferred staple food of all ethnic and cultural groups constituting the people of Sri Lanka. Providing sufficient rice for the population is a national concern. During the British colonial period Sri Lanka's economy was regulated to produce the export plantation crops of tea, rubber, coconuts and spices while the staple foods were imported. After independence the Department of Agriculture began a long-term effort to produce a self-sufficient amount of rice, while maintaining the export-oriented plantation sector of the economy. This effort continues to be the major concern of the Department of Agriculture, aimed at assisting the multitude of small farmers to obtain a better way of life while fulfilling the national production needs. An essential part of the effort is understanding the diverse physical conditions under which rice is produced so that proper technology can be applied for each individual environment.

For a small country, rice is produced under an exceptionally wide range of physical conditions. The country comprises one main pear-shaped island with a mountain hub in the broad southern part and is divided into three geographic elevation regions (Figure 1) that largely correspond to the three peneplains formed by telescopic block uplift during the geological history of the island. The upper two peneplains have since become strongly dissected. These geographic regions are:

- Low-country : below 300 meters
- Mid-country : between 300 and 1000 meters
- Up-country : above 1000 meters

The mountain hub interacts with the Northeast and Southwest monsoon air mass circulation to give the island a basic bi-modal rainfall distribution. This divides the year into two rainy seasons: Maha from October to January corresponding to the Northeast monsoon and Yala from April to August corresponding to the Southwest monsoons. The variation in the amount of these rains partition the country into three broad zones of wetness, referred to as Dry Zone, Intermediate Zone and Wet Zone.

Each rainfall zone is again subdivided into additional units. The various rainfall distribution sub-zones permutated across the appropriate geographic elevation regions have been demarcated on the national map to provide 24 agro-ecological regions (Land and Water Use Division, Department of Agriculture, 1979) in which the physical

environment is sufficiently different to have a major impact on both annual and perennial cropping. Most of these agro-ecological regions are clustered around the mountain hub.

Except for the very high elevations where temperatures are too cool, rice is grown in virtually all these agro-ecological regions. Most of the rice lands are in the low-country dry zone, where they are supported by tank irrigation schemes of various sizes. The rice lands are almost always relatively narrow tracts in the lowest portions of the landscape (Figure 1), and not the extensive alluvial plains generally used for rice through most of Asia, the exception being the few large irrigation schemes which provide sufficient water to blanket the area under command.

PREVIOUS SOIL RESOURCE STUDIES

Soil studies in Sri Lanka including rice land soils have been conducted and published over the last thirty years. Most of the early work was confined to the mineral soils in the low-country wet zone. Ponnamperuma (1959) applied the Kanno classification system with certain modifications in a survey of mineral soils in the low-country wet zone. Panabokke and Nagarajah (1964) reported on the fertility characteristics of rice soils throughout the country. Kawaguchi and Kyuma (1977) conducted a detailed study of 35 soils representing the more important rice-growing conditions in Sri Lanka.

Systematic soils survey work was initiated in 1960. Subsequently a soil map of Sri Lanka was compiled showing the aerial distribution of the great soil groups and associations. This was printed by the Survey Department for which a supporting text was prepared by de Alwis and Panabokke (1972). This concentrated largely on the upland soils considering the rice land soils as the hydromorphic variant of the more well-drained soils. In the more level low country this was expressed as the poorly drained members of general soil catenas, while in the more rugged mid-country and up-country the rice lands were generalized as homogeneous local alluvium or colluvium. Desaunttes et al. (1974) applied the land system approach to study the wet zone for diversification of uneconomic tea and rubber lands. Again the rice lands were dismissed as simply "mini-plains." The development of major irrigation schemes for large sections of the dry zone required high and medium surveys of the irrigated areas. This provided a basic knowledge of soils and landscape relationships in the dry zone and thus the country's most important rice lands.

Panabokke (1978) presented a general description and categorization of all rice lands in Sri Lanka including both low-country and mid-country. Besides indicating the need to understand how the systematic variation in the "mini-plains" and "local alluvium" of the mid-country rice lands was affecting rice production, this also broadly discussed the general relationship between the landscape and the hydrology of the narrow valleys of the mid-country in as far as this influenced the land qualities. The program was started in the mid-country portion of Kandy district where the general rugged terrain creates a highly complex physical situation and curtails the possibility of major capital development projects for the rice lands. This in turn restricts the cost/benefit ratio for a land evaluation study. The budget was therefore limited and forced some basic modification from typical Soil Resources Inventory (SRI) studies.

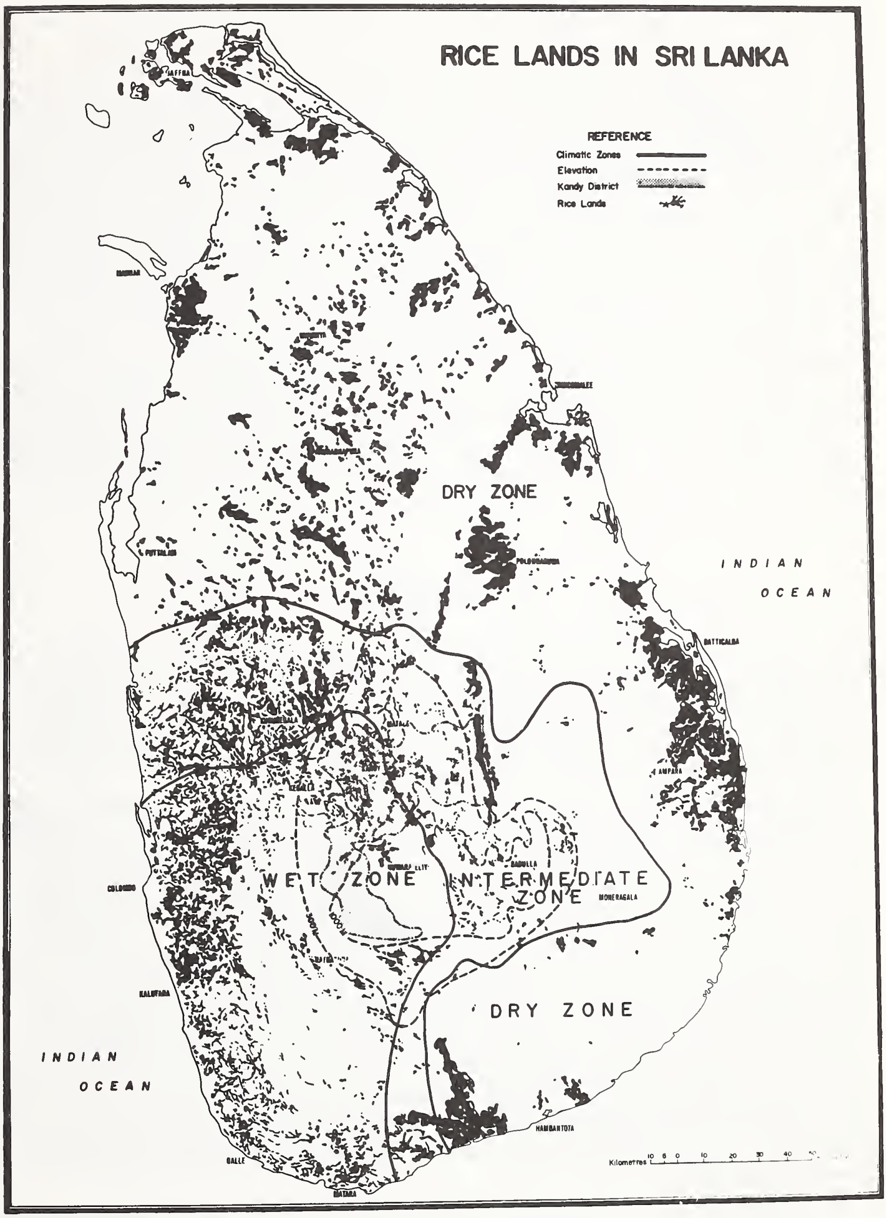


Figure 1. Rice Lands in Sri Lanka—Distribution in relation to climatic zones.

RICE LANDS IN KANDY DISTRICTS

Most of Kandy district (Figure 1) is in the mid-country surrounding the last pre-colonial capital of Kandy. This is approximately 110 km east of Colombo, at an elevation of 500 meters. The Kandy-Peradeniya area is the headquarters for the most technical agricultural services of the country. This includes the Faculty of Agriculture, Headquarters of the Department of Agriculture, Central Agricultural Research Institute and Botanical Gardens. There are approximately 20,000 ha of rice lands in Kandy district. These lands are largely found in small inland valleys nestled into the general mountainous area or on terraced mountain slopes. These two general types of rice lands correspond closely to the two geomorphic subdivisions of the middle peneplain. The inland valleys occur on the Kandy plateau portions and the terraced mountain slopes on the transition regions from the low-country to the mid-country, and from the mid-country to the up-country. A high percentage of the rice grown remains the indigenous varieties. When improved varieties were introduced in the district they grew poorly and in a patchy manner over large portions of the rice lands, indicating severe stress symptoms of various kinds. This focussed attention on the natural variability that was occurring in what was previously thought to be homogeneous lands and the need to determine the cause and predictability of problem areas in the landscape.

METHODOLOGY

The effort was essentially a single-purpose study focussed on wet rice culture. The determinants evaluated were those specific for paddy rice and concentrated on understanding the hydrological conditions of the different land units. However, hydrological conditions strongly interact with the entire landscape so that evaluating the rice lands requires understanding the adjacent uplands as well.

The method used for the study was a modification of Christian and Stewart's (1953) Australian "land system" approach, a land system being a physical area of uniform climate over which soils hydrology and land use occur in a predictable pattern. In this case the basic land units were identified on 1:63,360 (1 inch per mile) topographic maps in which the rice lands had been distinctly printed in green (Figure 2). The recurring patterns of rice lands are clearly apparent and readily allowed demarcation of basic land systems. The pattern of paddies on the topographic maps were then related to the five agro-ecological regions found in Kandy district (Figures 2 and 3). More detail on individual tracts was obtained from aerial photographs of 1:5,000 enlargement from contact prints of 1:40,000 or 1:20,000. Subsequently field visits to several tracts in each system were made for final evaluation and determining subdivisions of tracts and how these subdivisions fitted into the general landscape. The end result of the study was a four-tiered scheme of rice land classification with increasing specificity for successive categories (Table 1).

As the study progressed it became rapidly apparent that the depth of detail required to accurately delineate the subdivisions needed for adjusting production management in a normal SRI mapping would require a scale of 1:2,000 or 1:5,000. The cost of this would be prohibitive on a developing country's operational budget. At the same time it was noticed that many sub-units were recurring in an orderly manner within the

Figure 2. Land systems and sub-systems in different agro-ecological regions of Kandy district as seen against the topographic map with original scale at 1:63,360 and rice land printed in green.

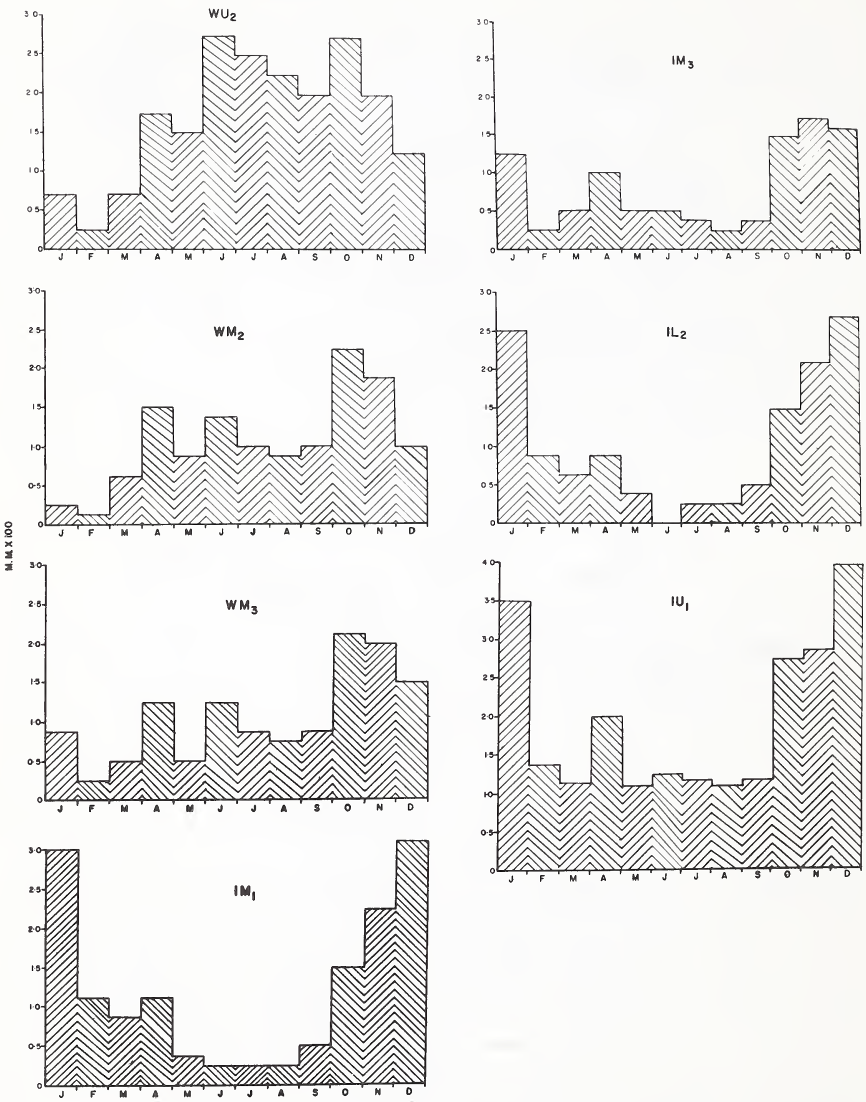


Figure 3. Rainfall distribution patterns at 75% expectancy for agro-ecological regions in Kandy district.

Table 1. Rice land classification scheme.

Land Category	Determinants/Components
I. SYSTEMS	Relief, Agro-Climate
II. SUB-SYSTEMS	Hydrology, Micro-relief Paddy/Upland Ratio Upland Soils Parent Material
III. RICE LAND COMPLEX	Individual Tracts —Inland Valleys —Terraced Slopes
IV. RICE LAND ELEMENTS	Inland Valleys —Valley Head —Valley Sides —Valley Bottom with Incised Drain —Valley Bottom without Incised Drain —Confluence Terraced Slopes —Concave Slope —Concave Contour —Straight Slope —Convex Slope —Convex Contour —Ridge Crest

general landscape of the individual tracts within the different systems. This allowed the study to avoid the costly, and what would have been a highly repetitive, effort of mapping each and every tract and concentrate on the economically easier approach of developing modal tracts for the different land systems. The various modal tracts were drawn illustrating how the various subdivisions' "land elements" systematically fit the landscape and how they would be easily identified by various simple techniques such as changes in size and shape of individual paddies, various degrees of wetness, physical strength of the soil, condition of the rice, etc. The modal tract illustrations were then used in field day presentations to agricultural specialists from both research and extension divisions. From this it was hoped that extension personnel could review similar tracts within the system, recognize the different land elements and assist the farmers in adjusting their management practices. Likewise it was hoped that research personnel would get a sufficient understanding of the problems to develop technology suitable for individual land elements in which adversities occur.

KANDY DISTRICT RICE LAND CLASSIFICATION SCHEME

The four categories in the rice land classification scheme are the "land system," "land sub-system," "rice land complex" and "rice land element" (Table 1).

Land system

This is the highest category. The land systems are first demarcated on the basis of agro-ecological regions. Rice lands in the mid-country part of Kandy district are found in five of the 24 agro-ecological regions of the country. These include WM_1, and WM_2 and WM_3 of wet zone, and IM_1 and IM_3 of the intermediate zone (Figure 3). Within the agro-ecological regions the land systems were demarcated according to recurring relief patterns in terms of height and width from crest to trough in the landscape. Eleven land systems were identified in this manner. Five of the eleven land systems are subdivided at the next lower category.

Land sub-system

This is the second category. The land sub-systems are demarcated by the determinants of the micro-environment. This includes (1) upland soils and their parent material, (2) ratio of rice to non-rice lands, (3) surface drainage patterns, (4) hydrology, (5) soil drainage, and (6) natural nutrient status. The six land systems that were not divided into sub-systems were uniform in these micro-environment determinants.

The characterization at the sub-systems level resulted in 21 land units. These were the limit of what could reasonably be mapped as distinct units. All the land systems and sub-systems were named after places, villages or regions well-known locally.

Rice land complex

This third category simply recognizes a contiguous tract of rice lands within a sub-system. They are generally lower order valleys or tracts of terraced slopes.

Rice land elements

This lowest category of the classification scheme recognizes sub-division of rice land complexes with sufficiently constant land qualities for uniform management over the entire element. For the most part, the different land elements define areas of different hydrological conditions within the complex. This separates areas of relative natural moisture enrichment from areas of relative moisture depletion, the extreme case of moisture enrichment being the artesian upwelling condition that is usually accompanied by severe stress problems in the rice.

In the inland valley complexes (Figure 4) rice land elements correspond to:

Valley heads
Valley sides
Valley floor with incised drainage
Valley floor without incised drainage
Confluences of valleys, etc.

In the hill and mountain terrace complexes (Figure 5) the rice land elements correspond to:

Concave contours
Convex contours
Straight slopes
Concave slopes
Convex slopes
Ridge crest, etc.

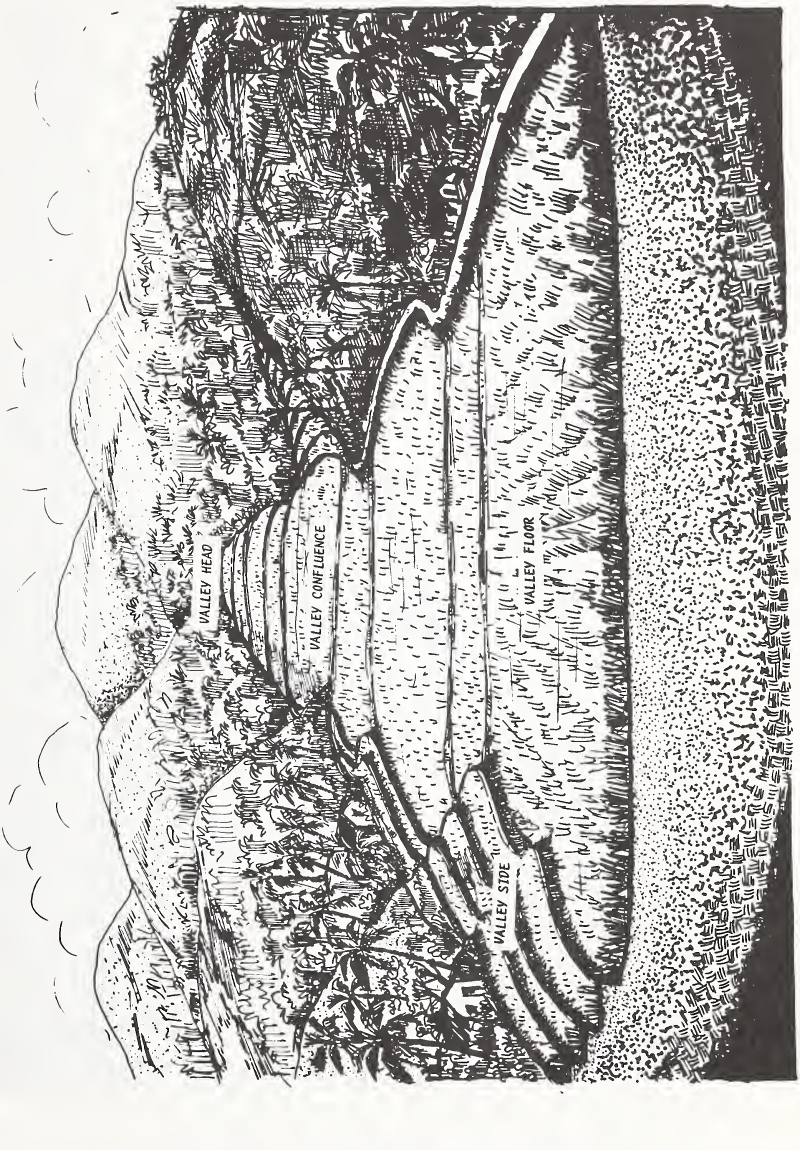


Figure 4. Land elements found in inland valley complexes.

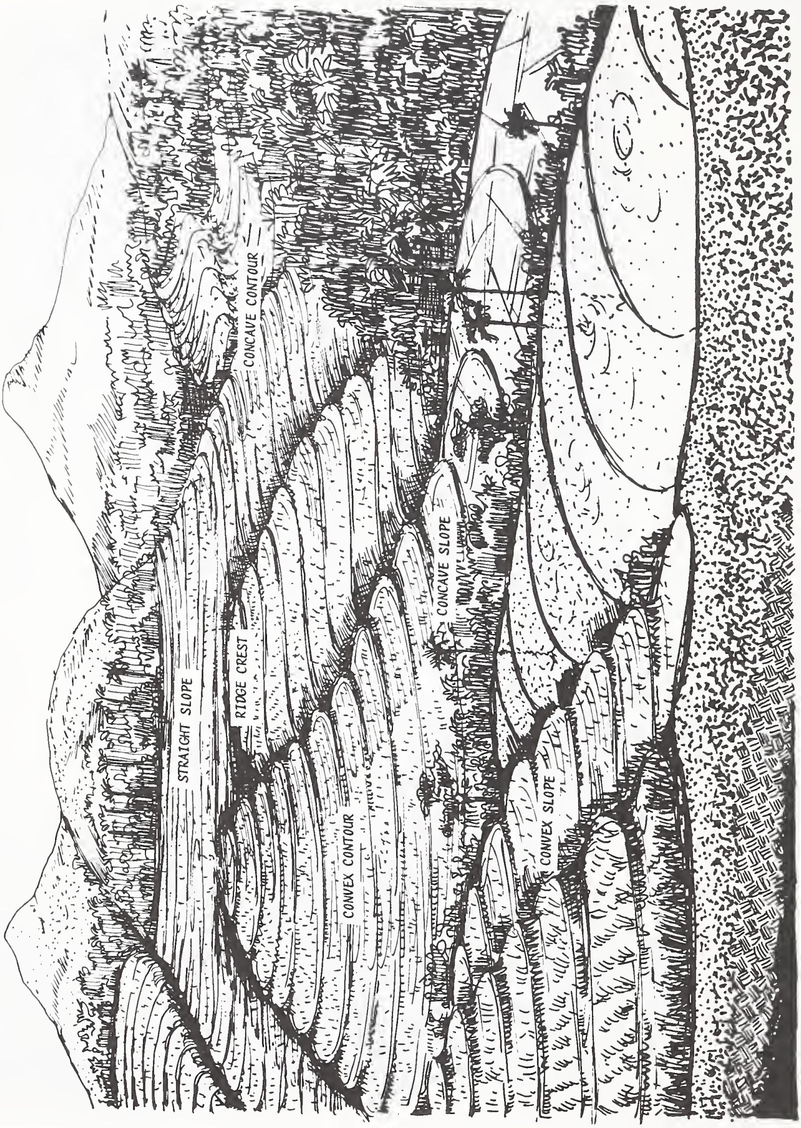


Figure 5. Land elements found in terraced slope complexes.

Generally in any given complex the number of land elements is limited to four or five. The same type of land element will reappear in similar complexes of different systems or sub-systems but assumes different agronomic values reflecting the changes in land qualities between different sub-systems and agro-ecological regions. For example, a valley side in a wet sub-system will be best suited for double cropping rice while the same element in a dryer sub-system will be suited for an upland rice cropping pattern.

LAND SYSTEMS AND LAND SUB-SYSTEMS IN KANDY DISTRICT

The individual land systems and land sub-systems in Kandy district are reviewed taking the systems with rice lands predominantly in inland valleys first, followed by those systems where rice lands are predominantly in terraced slopes. Land systems and sub-systems within each of the two groups are reviewed in the order of decreasing total wetness.

The four land systems in which the rice lands occur predominantly as inland valleys are:

1. Tumpane
2. Udunuwara-Yatinuwara
3. Harispathuwa, and
4. Hurikaduwa-Kundasale.

Except for the Hurikaduwa-Kundasale system all others have been subdivided into two to five sub-systems.

Tumpane land system (1)[1]

The Tumpane land system consists of moderate to high relief ridge or hill and valley landform patterns in the agroecological region WM_3. The valleys are commonly narrow and "V"-shaped. This particular land system has features common to both those of the plateau region and the transition region. The sub-systems are:

1a Alawatugoda-Ankumbura,
1b Hataraliyadda, and
1c Kolugala-Alagalla, respectively.

Alawatugoda-Ankumbura sub-system (1a). This sub-system consists of ridge or hill and valley landforms with moderate relief in the range 100 to 200 meters between trough and crest. Highlands consist of Reddish-Brown Latosolic soils (Rhodudults) with average slopes of 40–60%. Highlands are in tea and Kandyan mixed forest home gardens.[2] In this sub-system rice lands occupy approximately 15% of the total land area. The rice lands occur as long smooth central valleys with weak gradient (1–2%) along the axis, and variable width across, with smooth moderate gradient (2–10%) narrow side valleys. Both flat bottomed "U"-shaped valleys, and sharper bottomed "V"-shaped valleys occur. Some of the foothill slopes are terraced for rice.

[1]Numbers in parenthesis correspond to land system and sub-system numbers on Figure 2.
[2]Kandyan mixed forest home garden is an assortment of high value trees, shrubs and vines grown in and around homesteads. They are in reality a recreation of a multiple canopy rain forest with economically valuable plants. This would include cloves, nutmeg, coffee, cocoa, tropical fruits, pepper, jak etc.

Soils on the terraced slopes are moderately well drained whereas those soils in valley side elements or sloping elements are imperfectly drained and in valley floor elements the soils are gleyed and poorly drained. The drainage pattern is dendritic. This sub-system is the wettest of this land system. Annual rainfall is sufficiently high (>1250 mm at 75% expectancy) and the upland soil is deep enough to store sufficient water in highlands to maintain a high degree of wetness in the rice lands of the valleys and water flow in all streams during the limited dry periods. In most complexes this water has been diverted to provide local irrigation to side slope elements as well as across the valley bottom elements. The double cropping of rice is assured but flash flooding is a serious hazard in valley bottom elements.

Hataraliyadda sub-system (1b). This sub-system consists of ridge and/or hill and valley landforms with moderate relief, in the range of 100 to 200 meters between trough and nearest crest. Highlands consist of Reddish-brown Latosolic soils with average slopes of 40–80%. The highlands are in rubber, or Kandyan mixed forest home gardens. The rice lands occupy 15 to 20% of the land area. The rice lands are in stepped moderate gradient (2–3%) central valleys with smooth moderate to steep gradient (2–17%), narrow side valleys. Valley side elements and foothill slope elements have slopes up to 17%. Moderately well drained soils occur in foothill slope and valley side elements and poorly drained soils are in the valley floor, in steps and in very narrow valley elements. The drainage pattern is dendritic and streams are incised. The annual rainfall is high (>1250 mm at 75% expectancy) and the upland soils are deep enough to store a greater part of the rainfall which keeps the valleys well supplied with water and the streams flowing continuously. Double cropping of rice is assured but flash flood hazards occur in central valleys.

Kolugala-Alagalla sub-system (1c). This sub-system consists of ridge and/or hill and narrow valley landforms of high relief in the range of 200 to 400 meters from trough to crest. The highlands consist of Reddish-Brown Latosolic soils with average slopes of 40–60%. Highlands are in tea, rubber and Kandyan mixed home gardens. The rice lands occupy approximately 5% of the land surface. The rice lands occur as terraced hill slopes because the valleys are too narrow and "V"-shaped to asweddumize[3]. The drainage pattern is dendritic. the annual rainfall is high (>1250 mm at 75% expectancy). The dry weather flow in second order streams is moderate but sufficient to provide the terraced slopes with supplementary irrigation from diversions. Double cropping of rice is assured without serious problems. New high-yielding varieties are adopted throughout this sub-system.

Udunuwara-Yatinuwara land system (2)

The Udunuwara-Yatinuwara Land System consists of low relief ridge and/or hill and valley, plus isolated hillock landforms in the agro-ecological region WM_2. This land system is completely within the Kandy plateau region. On the south and east boundaries are mountainous land masses and on the north and west boundaries are steeply dissected mountainous slopes. The physical environment has a high degree of variability within the system. Therefore, the land system is divided into five sub-systems (Figure 6).

Ganhata Sub-system (2a). This sub-system consists of hill and/or ridge and valley land forms with moderate relief, in the range 100–200 meters. The soils of the highlands

[3]Asweddumization is the process of land development and land formation with perimeter bunds, etc. to suit wetland rice cultivation.

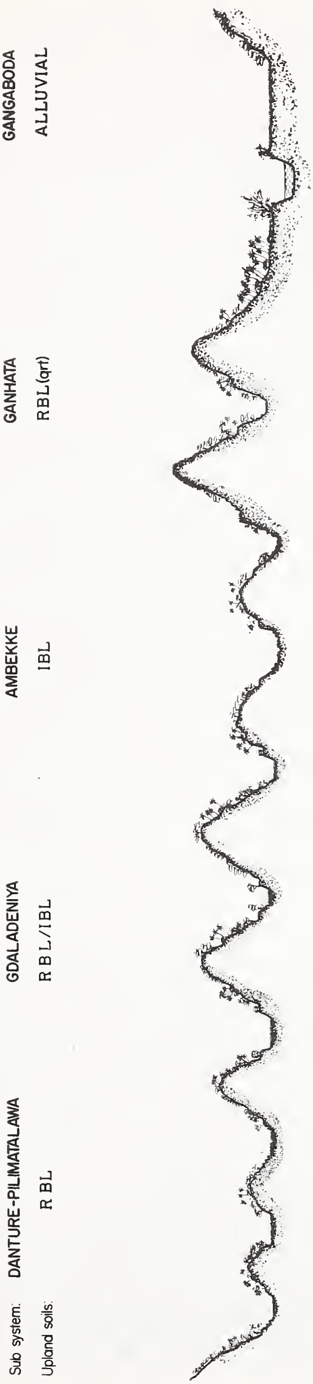


Figure 6. Transect of sub-systems of the Udunuwara-Yatinuwara land system.

are Reddish-Brown Latosolic and the average highland slopes range from 30 to 65 percent. The highlands are in tea and Kandyan mixed forest home gardens. The rice lands occupy approximately 20% of the land area. They are in smooth, weak gradient (1–3%) long narrow central valleys with narrow side valleys of moderate gradient (4–5%): in isolated suspended valleys resembling amphitheatre-like structures towards valley heads; and in terraced slopes of 2–30% on both valley sides and foothill slopes. Moderately well drained, strongly mottled soils occur on terraced slope elements; imperfectly drained soils occur on mid-slope and valley head elements and the poorly drained gleyed soils occur on bottom land elements of basin type valleys and narrow valleys in the absence of incised streams. The annual rainfall is high (>1375 mm at 75% expectancy). The proportion of highland and the soil depth in the highlands is high enough to store enough rainfall to keep valleys well supplied with water. Double cropping of rice is assured. Interflow and upwelling conditions appear to cause nutrient imbalances in the confluence of valleys and bottom of suspended valleys. The flash floods in central valleys are an additional hazard.

Gadaladeniya sub-system (2b). This sub-system consists of ridge and/or hill and valley, and hillock landforms with low to mderate relief (30–200 meters). The highlands consist of Reddish-Brown Latosolic soils or Immature Brown Loams (Inceptisols). The average highland slopes range from 20 to 40%. They are in tea or Kandyan mixed forest home gardens. The rice lands are mainly in stepped weak gradient (1–2%) long narrow or long irregular width, central valleys with narrow side valleys of moderate gradient (2–7%). The valleys are flat bottomed or "V"-shaped. Some foothill slopes and valley sides are terraced for rice. Moderately well drained soils occur on valley side and foothill slope elements, whereas imperfectly drained soils are in midslopes, valleys of moderate gradient or in valleys with incised drainage. The poorly drained soils are gleyed from the surface, and occur in valley step elements and narrow valley elements in sections of moderate relief. The drainage pattern is trellis with prominant bedrock control. The annual rainfall is high (>1375 mm at 75% expectancy). Both the low relief and the shallow soil depth cause lower moisture storage in the highlands than in the Ganhata sub-systems and the dry weather flow is very low. The hydrological conditions are good enough for double cropping rice with slight drought risk. In late Maha season flash floods in higher order valleys and interflow in steps are additional hazards to rice production.

Gangaboda sub-system (2c). This sub-system is a narrow alluvial terrace of the Mahaweli Ganga probably formed in a much earlier time in the history of the landscape. Along the boundaries of the alluvial terrace are mountainous land masses at the foot of which are alluvial cones and fans. The entire sub-system is in rice. The soils are moderately well drained alluvial with some slope colluvium. The streams that originate in the wetter highland cut through the sub-system. Diverting of these streams provide a plentiful water supply for the whole sub-system to be cropped with rice or upland crops. Occasionally (1 year in 15–20) high floods are a major hazard. High-yielding varieties are adaptable throughout the sub-system.

Danture-Pilimatalawa sub-system (2d). This sub-system consists of hill and valley, and rounded hillock landforms of low relief in the range of 30 to 100 meters. On the highlands are Reddish-Brown Latosolic soils with average slopes ranging from 6 to 30%. The highlands are in tea or Kandyan mixed forest home gardens. The rice lands occupy nearly 50% of the land area. The rice lands are in smooth weak gradient (1–2%) central valleys with side valleys of moderate gradient (4–7%). These side

valleys are either narrow and smooth or stepped. There is a very limited extent of hill slope terracing towards some of the valley heads. Moderately well drained soils occur in terraced slope or in valley side elements. The imperfectly drained soils are in greatly sloping valley or in valley bottom elements with incised drainage. The soils are gleyed and poorly drained in steps of valleys, narrow valleys and flat valley bottom elements in the absence of incised drainage. The drainage pattern is dendritic. The annual rainfall is high (>1475 mm at 75% expectancy). The first order valleys and steps of valleys are well supplied with water. The valley bottom tends to dry up in late February–March. During the limited dry periods supplementary irrigation is made available through stream diversions. A very high percent of the rice lands are double cropped. However, late sown rice in Maha season may suffer from water shortage in valley bottom elements at the lower ends, the valley side elements and hill slope elements. Interflow and upwelling in valley step elements appears to cause nutrient imbalance of deficiencies in Maha season. Flash floods are a hazard in valley bottoms.

Ambekka sub-system (2e). This sub-system consists of hill and valley, and hillock landforms of low relief in the range of 30–100 meters. The soils in highlands are Immature Brown Loams. The average land slopes are in the range 10–30%. These lands are in Kandyan mixed forest home gardens. The rice lands occupy about 40% of the land area. The rice lands are in smooth weak gradient (1–2%) long central valleys with moderate gradient (3–5%) narrow side valleys. There are some bedrock control features; the first order valleys towards the valley head are stepped. The moderately well drained soils occur in valley side elements, whereas imperfectly drained soils occur in midslopes of valleys with moderate gradients. The soils in valley bottoms, steps of valleys, and narrow valleys are gleyed and poorly drained. The drainage pattern is dendritic with incised streams in the higher order valleys. The annual rainfall is high (>1375 mm at 75% expectancy). The moisture storage in the highlands is low as a result of low relief, large percentage of rice land and shallowness of highland soils. There is very little dry weather flow in streams. The well drained and imperfectly drained soils require supplementary irrigation in late Maha season. Yala season is good only for upland crops. Flash floods are a hazard in the sub-system.

Harispattuwa land system (3)

The Harispattuwa land system consists of hill and valley, and hillock landforms of low relief, in the agroecological region WM_3. The land system is entirely within the Kandy plateau. It is bounded by ridges of moderate relief on the north and south, moderate to high relief ridges on the southwest, and by a steeply dissected slope on the west. The land system is divided into three sub-systems:

- 3a Medawala-Bokkawala
- 3b Kulugammana, and
- 3c Talawinna.

Medawala-Bokkawala sub-system (3a). This sub-system consists of hill and valley, and hillock landforms of low relief in the range of 30 to 100 meters from trough to the nearest crest. The soils on the highlands are Immature Brown Loams with the average slopes ranging from 20 to 40%. The highlands are in tea and Kandyan mixed forest home gardens. The rice lands occupy about 40% of the land area. The rice lands occur in weak gradient (1–2%) long smooth central valleys with stepped moderate gradient (2–7%) narrow side valleys. Some valley sides up to 10% slopes and foothill slopes up

to 10% gradient are terraced for rice. The valleys are "U"-shaped. Moderately well drained soils occur on valley side elements, hill slope elements and along incised streams, the imperfectly drained soils occur on valley head elements, moderately sloping valleys closer to streams. The poorly drained soils, gleyed from surface, occur in steps of valleys. The drainage pattern is dendritic. The annual rainfall is moderately high (>1250–1375 at 75% expectancy). A low but steady dry weather flow is maintained in streams. Rice is double cropped but the drought risk is high. Interflow in valley heads and steps appears to cause nutrient imbalance of deficiencies. Flash floods are a common hazard.

Kulugammana sub-system (3b). This sub-system consists of hill and valley, and hillock landforms with low relief, in the range of 30 to 100 meters from the trough to the nearest crest. The soils on highlands are Immature Brown Loams and the average highland slopes range from 20 to 55%. The highlands are in Kandyan mixed forest home gardens or in tea with some spice crops. The rice lands occupy approximately 30% of the land area. These rice lands occur in stepped weak gradient (1–2%) narrow central valleys with stepped moderate gradient (2–5%) narrow side valleys. Some of the rice lands are located in terraced foothill slopes up to 12% gradient with limited extent in valley side slopes. Moderately well drained soils occur on foothill slope elements and valley side elements, whereas imperfectly drained soils are confined to valley head elements, mid-slope elements or stepped valleys and valley floor elements with incised drainage. The poorly drained soils occur on valley step elements and narrow valleys. The drainage pattern is dendritic but with some bedrock control of the valleys. The annual rainfall is moderately high (>1250–1375 mm at 75% expectancy). The storage in the highlands is low because of low relief and shallowness of soils. Dry weather flow in the streams is very low and the water supply to valleys is limited. Rice is double cropped to a limited extent with vegetables during Yala season in valley side elements and foothill slope elements. The drought risk is high throughout the sub-system.

Talawinna sub-system (3c). This sub-system consists of hill and valley, and hillock landforms with low relief in the range of 30 to 100 meters between the trough and nearest crest. The soils on highlands are Immature Brown Loams. The average highland slopes are in the range of 20–30%. The highlands are in Kandyan mixed forest home gardens. The rice lands occupy about 20% of the land area. The rice lands occur in stepped weak gradient (1–2%) narrow central valleys with stepped, moderate gradient (2–5%) narrow side valleys. A limited extent of valley sides are terraced for rice but foothill slopes up to 10% gradient are terraced. Moderately well drained soils are in valley side elements and foothill slope elements whereas the imperfectly drained soils are in mid-slope and valley head elements. The poorly drained soils occur in steps. The drainage pattern is dendritic. Strong bedrock control, though not expressed in the drainage, is evident in the valley form. The annual rainfall is >1250–1375 mm at 75% expectancy. The moisture storage in the highlands is limited because of the shallowness of soils and low relief. Dry weather flow is very low in the streams. Double cropping of rice in this sub-system is the common practice, but the drought risk is high.

Kundasale-Hurikaduwa land systems (4)

This land system consists of hill and valley, and hillock landforms in the agro-ecological region IM_3 within the Kandy plateau region. The relief is low in the range of 30 to 100 meters from trough to crest in the landscape. On the northern, eastern and

western boundaries of the land system are ridges of moderate relief with an elevation difference in the range of 100–200 meters. This land system is not subdivided at the next lower category. The soils of the highlands consist of Immature Brown Loams. The average highland slopes are in the range of 15–30%. The highlands are mainly in cocoa, coffee, coconuts, and pepper. The rice lands occupy about 20% of the land area. They occur in stepped weak gradient (1–2%) long central valleys with moderate gradient (2–5%) side valleys. A limited extent of valley sides and foothill slopes are in rice. Moderately well drained soils occur on valley side, foothill slope, sloping valley elements and weak gradient valley elements. A limited extent of poorly drained soils are in valley step and slope elements with continuously flowing irrigation channels on upper contours. The drainage pattern is dendritic. The rainfall is between 875–1250 mm. The storage in the highlands is low because of the shallowness of soils and low relief. Dry weather flow in streams is low and frequently ceases during Yala season months of May to September. Rice is double cropped in land elements with poorly drained soils and the valley side elements and foothill slope elements with irrigation. Most commonly, rice is grown in Maha season in all rice lands and other crops in Yala season in the land elements with moderately imperfectly drained soils. The drought risk is high in this land system.

The seven land systems in which rice lands occur predominantly on terraced mountain or hill slopes are:

5. Atabage
6. Dolosbage-Nawalapitiya
7. Narampanawa
8. Uduwela-Pallegama
9. Teldeniya-Madugoda
10. Talatuoya-Marassana, and
11. Talagune.

Of these the Dolosbage-Nawalapitiya and Teldeniya-Madugoda systems are subdivided into two sub-systems each. These systems and sub-systems are spread over both the wet and intermediate zone parts of the district. As mentioned previously the terraced systems are in transitional regions between the Kandy plateau and the upper and lower peneplains; the wet zone systems are transitional to the upper areas, while the intermediate zone systems are transitional to lower areas.

In evaluating rice lands on terraced slope systems the determinants of the percentage of rice lands in the system (Figure 7) and the extent of terraces on a given slope have not been fully examined. However, it is observed that the physical determinants of rock structure stability, soil depth, and percent of slope influence the ability to form stable terraces of workable size on a given slope. Also the availability of water in the upper catchment above the terraces for diversion as a local irrigation system influences the extent of terracing on a slope. In some cases the priority of land use for large tea estates constricts some potentially terraceable lands. All this generally makes the terraced land systems less extensive than the corresponding inland valley systems.

Atabage (5)

Atabage is a highly dissected, very steep hill and valley landform of high relief (200–400 mm) in the agro-ecological region WM_2. The highlands consist of Reddish-Brown Latosolic and Red Yellow Podzolic (Ultisols) soils with average slopes of

Figure 7. Schematic illustration of a terraced slope rice land complex.

40–70%. The highlands are planted in tea, patna grasslands, and Kandyan mixed forest gardens. The rice lands constitute only 5% of the total land area. They are found on the less sloping (<25%) lower slopes of narrow valleys. A small extent of the rice lands in the system are in moderately broad valleys and alluvial terraces. The well drained rice land soils are found in the more steeply sloping convex slopes while the imperfectly drained soils occur in valleys and terraced slope elements below the irrigation channels. The overall drainage is dendritic and rice lands are generally very wet. Double cropping of rice is assured, but generally because of excessive wetness and upwelling conditions on lower parts of the complex, only low-yielding indigenous varieties are used. Improved varieties are restricted to well drained areas, but their yield potential is frequently reduced by heavy cloud cover. Also harvesting of rice is frequently affected by nearly continuous light rains.

Dolosbage-Nawalapitiya (6)

This land system consists of an elevated but steeply dissected secondary plateau, and the escarpment leading from the main Kandy plateau up to the secondary plateau. It is also in agro-ecological region WM_2. The land system is divided into the two subsystems Dolosbage and Ulapane-Nawalapitiya, representing the plateau and escarpment parts respectively.

Dolosbage (6a). This is the plateau portion of the system. It represents the highest rice lands in the district and the upper limit of the middle peneplain. The original plateau has been dissected until it is now a landform consisting of high relief (200–400 m) hill and /or ridge and valleys. Highland soils, slopes and land use are similar to the Atabage system. The rice lands occupy about only 10% of the total land surface, with the remaining almost exclusively in tea. The rice lands are essentially the lands too wet for tea and are composed of isolated suspended basin type valleys, smooth narrow valleys of strong gradient, and terraced hill and mountain slopes. Well drained rice land soils are limited to the upper terrace slopes, while imperfectly drained soils occur on the bottom lands of the basin valleys. Both the surface and sub-surface inflow of water into the basin valleys remain high even during limited dry periods. This results in a large percentage of the bottom lands having upwelling conditions and low support strength. Most terraced areas are supplied with irrigation water from stream diversion. The bottom lands are double cropped generally with old improved varieties, while the hill slopes without irrigation are mostly single cropped with indigenous long age varieties. When irrigation is available double cropping occurs with old improved varieties. Few areas are suitable for new improved varieties. As in the Atabage system continuous rains frequently hinder harvesting activities.

Ulapane-Nawalapitiya (6b). This is a small sub-system comprising the escarpment portion of the land system. The rice lands cover about 20% of the area. They consist of a line of alluvial fans and cones at the root of the escarpment plus the alluvial terraces on both sides of the stream at the bottom of the escarpment. Sub-surface water flow through the alluvial fans, cones and inner alluvial terrace cause almost all these soils to be poorly drained with only isolated patches of imperfectly drained soils. Moderately well drained soils occur only on the other alluvial terrace. Upwelling problems occur throughout much of the fan and cone portion of the sub-system. A continuously flowing irrigation canal is found along the top of the alluvial cones and fans that provides irrigation so that the entire sub-system is double cropped. New improved varieties are used on the outer terrace while old improved varieties on the poorly drained remainder.

Narampanawa (7)
This system consists of a hill and valley landform of high relief (200–400 m) in the slightly drier agro-ecological region WM_3. On the north and east is a mountainous landscape while on the south and west is a lower relief range. The highland soils are Reddish-Brown Latosolic derived from quartzitic parent materials. The highly quartzitic parent material has resulted in soils of generally low fertility throughout the land system, and are responsible for the abandonment of several terraced rice land complexes. The highlands have an average slope of 35–60% and are used mainly for poor quality tea, with some Kandyan mixed forest gardens. Coconut in many of the gardens show yellowing typical of Mg deficiency. Rice lands occupy about 5% of the land surface. They occur mainly on steep mountainous slopes and foothill slopes with a small component in narrow sloping inter-hill valleys. The soils would be similar to the upland soils except for the artificial hydromorphism induced by local diversion irrigation schemes. The well drained rice land soils occur on convex contour elements with the imperfectly drained soils on straight slope and mid-slope elements; poorly drained soils are on concave slope elements and in the inner hill valleys. The overall drainage pattern is dendritic. All rice lands are supplied with ample irrigation so double cropping is assured with high-yielding varieties adaptable to most areas. However, the low inherent fertility limits their full yield potential from being obtained. Slumping can be a major hazard.

Uduwela-Pallegama (8)
This system is a landform of warped basins enclosed by moderate to high relief ridges; narrow "V"-shaped, downcutting valleys in the agro-ecological region WM_3. Highland soils are Reddish-Brown Latosolic. The average highland slopes are30–80%. The highland land uses are tea, Kandyan mixed forest gardens, patnas[4] and conservation forest. The rice lands occupy about 5% of the land surface, and occur on lower terraced hill and mountain slopes. Moderately well drained rice land soils occur on convex slope elements, while the imperfectly drained soils are on straight slope, mid-slope elements, etc. The poorly drained soils are in concave contour and concave slope elements. An exception is the convex contour slope elements with perennial irrigation channels on upper contours. The rainfall is similar to the Narampanawa system, but the dry weather flow is somewhat less. The double cropping of rice is assured for most elements with a slight drought risk on strongly sloping elements in Yala. Upland crops are grown on less than 10% of the rice lands in Yala season. These are concentrated on the drier convex contours or convex slope elements.

Teldeniya-Madugoda (9)
This land system is a landscape of parallel and sub-parallel ridges and narrow valleys and hills, with the relief of 200–400 m. The system is in the agro-ecological region IM_3, with a 75% expectant rainfall of 875 mm per annum. This system has been divided into the two sub-systems:

1. Teldeniya
2. Madugoda

Teldeniya (9a). This sub-system consists mostly of a ridge and/or hill and narrow valley landforms. The highland soils consist of Reddish-Brown Latosolic and Imma-

[4]Patnas: Natural low productive grasslands, the origin of which is not definite.

ture Brown Loams and the highland slopes average 30–60%. The highland land use is tea, Kandyan mixed forest gardens, and tobacco. The rice lands occupy about 5% of the land surface. These lands are in terraced steep mountain slopes and hill slopes. The strongly sloping convex contour and convex slope elements contain the well drained soils, while the concave contour and concave slope elements contain the poorly drained, and the straight mid-slope elements consist of imperfectly drained soils. The flow in streams is seasonal and the drainage pattern is dendritic. Local irrigation systems are developed by diverting the creeks formed in the concave contours along the upper contour to supply water for most of the complex during Maha season, but only to a limited amount during Yala season. Thus double cropping rice is restricted to the concave contour areas near irrigation sources while remaining lands are cropped to vegetables.

Madugoda (9b). This sub-system consists of a primary ridge with parallel secondary ridge and/or narrow valley landform. The highland soils are Red Yellow Podzolic and Mountain Regosols with average slopes of 25–65%. Highland use is confined to a few home gardens, with most of the land in conservation forest. The rice lands occupy about 5% of the total land surface. They occur either as suspended gently sloping secondary ridge crests irrigated with water collected from the primary ridge, or gently sloping inter-ridge foot slopes irrigated by stream diversion. Remaining lands appear too steeply sloping for terrace development. The pattern of soil drainage classes is similar to the Teldeniya sub-system. Stream flow remains seasonal except for third order streams which have a low continuous flow during extended dry periods. Except in poorly drained land elements near irrigation sources, rice is grown only in Maha season. Unlike the Teldeniya sub-system, heavy winds in Yala season drastically limit the Yala cropping potential to the limited extent of vegetables.

Talatuoya-Marassana (10)

This land system consists of secondary ridges and valleys of moderate relief bound by the high relief primary ridge on the south and southeast in the agro-ecological region IM_1. The highland soils are Reddish-Brown Latosolic and Rendzina (Udoll). The average highland slopes range from 10–50%. Highlands are in tea, tobacco, mixed home gardens, and vegetables. The rice lands occupy about 15% of the land area. They occur in highly dissected ridge slopes and foot slopes, and smooth moderate gradient (2–5%) central valleys with side valleys of moderate gradient (5–8%). Moderately well drained soils occur on convex contour slope elements and concave contour slope elements. The annual rainfall is moderately high. The drainage pattern is dendritic to sub-parallel and streams are incised. The dry weather flow is moderate and steady. Most commonly Maha season rice is followed by vegetable crops. The drought risks in Yala season are high. Rice is double cropped only in situations where the soils are unsuitable for other crops and supplementary irrigation is available.

Talagune (11)

This land system consists of parallel or sub-parallel ridges and narrow valleys in the agro-ecological region IM_1. The relief in the region is high. The highland soils consist of Red Yellow Podzolic and Mountain Regosols. Average highland slopes are 25–55%. The highland is restricted to a few home gardens in which tobacco is a major component. Most of the region remains in some form of forest cover or patna grasslands. The

rice lands occupy about 10% of the land area. These lands occur on terraced mountain and foothill slopes or rounded convex crest of ridges whose sides are too steeply sloped for terracing. The soil pattern is very much similar to that of the Madugoda subsystem. The rainfall is moderately high; the drainage pattern is subparallel to rectangular. Dry weather flow is low but steady only in major streams. Double cropping of rice is possible on poorly drained land elements, while rice is grown on all land elements during Maha season. Heavy Yala season winds are a hazard in this system as in the Madugoda sub-system. Short-term drought risks are high in both Maha and Yala seasons. The cropping calendar is delayed compared to the other land systems.

SUMMARY AND CONCLUSION

This paper illustrates an SRI effort to evaluate the systematic variation in the rice land sub-portion of a rugged mountain district. The rice lands are scattered across most of the numerous landforms in the district but comprise less than 25% of the total surface area. Using extensive field observations of physical determinants for rice culture, topographic maps, and aerial photographs a four-tiered rice land classification scheme was developed based on the land systems approach. This scheme made it possible to focus on the rice lands and the variability in them. In the final analysis it was possible to recognize why advanced varieties could only be used in limited areas and why preference had been given to indigenous or old improved varieties. It was also possible to predict where in a given complex of a system various problems would most likely occur.

The land qualities of the lowest category in the classification, 'the land elements,' is highly specific. In any land system or sub-system the evaluation of this basic unit would be in terms of biological responses and specific management requirements. This would provide sufficient guidance to research indepth studies on specific problems, particularly those problems associated with widely varying hydrological conditions. Further, the knowledge of individual land elements and their relationships to the modal land complexes of a given land system provide guidance to the extension services to improve their understanding of the system in terms of the potentials, limitations, and variable management needs. The flow of information from the SRI stage to the utilization stage is very rapid at minimum cost.

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LITERATURE CITED

Christian, C. S., and G. A. Stewarts. 1953. General report on survey of Katherine-Darwin Region, 1946. Land Research Series No. 1, CSIRO, Australia.

De Alwis, K. A., and C. R. Panabokke. 1972. Handbook of soils of Sri Lanka. J. Soil Sci. Soc. Ceylon, 2:1–97.

Desauntees, J. R. et al. 1974. Methodology proposed for land evaluation in the wet zone of Sri Lanka. Trop. Agric. 130:135–153.

Panabokke, C. R., and S. Nagarajah. 1964. The fertility characteristics of rice growing soils of Ceylon. Trop. Agric. 120:3–30.

Panabokke, C. R. 1978. Rice soils of Sri Lanka. p. 19–33. *In* Proceedings of Symposium on Soils and Rice, IRRI. Los Baños, Laguna, Philippines.

Ponnamperuma, F. N. 1959. A scheme of classification for the mineral rice soils of Ceylon. Int. Rice Cong. Sessions, Peradeniya.

Kawaguchi, K., and K. Kyuma. 1977. Characteristics of paddy soils in each country. p. 156–187. *In* Paddy soils in tropical Asia. Their mutual nature and fertility monographs of the Center for South East Asian Studies, Kyoto University. The University Press of Hawaii, Honolulu.

PART ONE

SOIL RESOURCE INVENTORIES

Section III

Nature of Soil Resource Information Needed by Planners

The Role of Water and Land Resource Information in World Bank Programs for Agricultural Development[1]

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Water and land resource development and maintenance are of paramount importance in meeting the food, fiber, and energy crises and helping man. This paper summarizes the role of water and land resource information in meeting this challenge by World Bank programs for agricultural development. The paper briefly describes the purpose and activities of the Bank along with the nature, diversity, and scope of financed projects; requirements with respect to basic data, evaluation, and product from the standpoint of an international financing agency; factors in addition to soil that need to be taken into account, kept in perspective, and integrated; preferred approaches to land selection; the need for streamlining investigations; and principal deficiencies in surveys as commonly made in meeting needs. The paper emphasizes that data collection and land selection need to be approached as an interdisciplinary exercise wherein contributions are made by economists, hydrologists, drainage engineers, agronomists and others. The importance and usefulness of screenable soil characterization as a tool for support of studies is also stressed. Ways and means are suggested whereby soil surveyors may produce a better product by becoming more involved and taking an expanded role in the planning process.

THE WORLD BANK—BACKGROUND[2]

Along with the International Monetary Fund (IMF), the International Bank for Reconstruction and Development (IBRD or World Bank) was founded in 1944 at the United Monetary and Financial Conference of 44 governments at Bretton Woods, New Hampshire, USA. These were established as complementary, international finance

[1]The views expressed in this paper are those of the author and not necessarily those of the World Bank.

[2]Based on World Bank Reports and Publications namely: World Bank/Annual Report 1978; The World Bank, December 1977; The World Bank—Questions and Answers, March 1976; World Bank—International Development Association, April 1978; The International Finance Corporation/Annual Report 1978; and the paper by Mr. Frederick L. Hotes, World Bank Irrigation Adviser entitled: "World Bank Activities in Financing International Water Resources Efforts" presented at the 1977 Annual Meeting of the University Council on Water Resources, Brookings, South Dakota, USA, July 26, 1977.

institutions to meet needs of international cooperative agreements to deal with monetary and financial problems by providing the machinery that would enable nations to work together toward world prosperity, thereby aiding political stability and fostering peace among nations.

Although their joint objective as stated above is the same, their roles differed. As indicated by the formal titles, the Fund's main concern is with monetary affairs, and the IBRD's with economic development. The main objectives of the Fund — the promotion of international monetary cooperation, the encouragement of expansion and balanced growth in international trade, the promotion of exchange stability, the elimination of exchange restrictions, and the correction of balance of payments disequilibria—complement the IBRD's efforts to promote economic growth in member countries through its loans for productive development projects. The two institutions cooperate closely on operational and analytical matters, hold joint annual meetings, and are housed in neighboring buildings in Washington, D.C.

Membership in IBRD is open to all members of the IMF, and by June 30, 1978, 132 countries had joined. IBRD is owned and controlled by its member governments. By a formal agreement in accordance with the United Nations (UN) Charter, it is recognized as a special Agency of the UN. It began operations in June 1946.

The World Bank is now a group of three institutions, the International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), and the International Finance Corporation (IFC). The common objectives of these institutions are to help raise standards of living in developing countries by channeling financial resources from developed countries to the developing world.

Sources of funds

IBRD makes or guarantees loans for productive reconstruction and development projects, both from its own capital, which is provided by its member governments, and through the mobilization of private capital. IBRD's share capital is so structured that any risk involved in its operations is shared by all member governments, roughly in proportion to their economic strength. Capital subscription on June 30, 1978 aggregated the equivalent of about 41,016 million in current U. S. dollars. Only ten percent of the capital has been called and paid in; the remaining ninety percent is subject to call by IBRD only if and when required to meet the obligations of IBRD created by borrowing or guaranteeing loans. Thus, investors, i.e. member countries who might otherwise never become involved in the financing of projects directly, are contributing to the economic growth of developing countries.

Lending operations are financed in the world capital markets including private investors, governments, and central banks. Aside from borrowings, paid-in capital subscription, and charges on its loans, IBRD has two other principal sources it can lend. Most important is the flow of repayments on previous loans. In addition it often sells portions of its loans to other investors, chiefly commercial banks. Profit or net earnings are also used to help developing countries by placing these in reserves which strengthen ability to borrow and making reserves available for lending.

To maintain the confidence of both member governments and the international finance community and thereby enable a continued source of funds for development, IBRD carefully appraises all aspects of projects submitted to it for financing. Thus, the planning of projects and analyses must be technically and economically sound. Studies, particularly water and land resources investigations, must be relevant and of

the highest quality commensurate with objectives. IBRD also periodically reviews the execution and operation of those projects which it helps finance, and provides advice and assistance to the borrower in the attainment of project objectives.

IBRD's role as a prudent lender is directed to be in the best interests of all concerned: member governments, lenders to IBRD, and borrowers. The performance of IBRD and its borrowers in the use and repayment of the invested and borrowed capital so far continued to find general approval of the world financial community, as demonstrated by their continued willingness to provide needed resources to IBRD.

IBRD loans

IBRD's charter spells out certain basic rules that govern its operations. It must lend only for productive purposes and must stimulate economic growth in the developing countries where it lends. It must pay due regard to the prospects of repayment. Each loan is made to a government or must be guaranteed by the government concerned. The use of loans cannot be restricted to purchases in any particular member country. And IBRD's decisions to lend must be based only on economic considerations.

IBRD loans generally have a grace period of five years and are repayable over 20 years or less. They are directed toward developing countries at more advanced stages of economic and social growth. The interest rate the Bank charges on its loans is calculated in accordance with a formula related to its cost of borrowing.

While IBRD has traditionally financed all kinds of capital infrastructure, such as roads and railways, telecommunications and ports and power facilities, its present development strategy places a greatly increased emphasis on investments that can directly affect the well-being of the masses of poor people of developing countries by making them more productive and by integrating them as active partners in the development process. This strategy is increasingly evident in the agricultural and rural development projects that IBRD and IDA help finance. It is also evident in projects for education, family planning, and nutrition, and in the Bank's concern for the urban poor who benefit from projects designed to develop water and sewerage facilities as well as "core" low-cost housing, and to increase the productivity of small industries.

At the same time, lending for traditional projects continued, and is being redirected to be more responsive to the new strategy of deliberately focusing on the poorest segments of society in the developing countries.

IDA

The International Development Association was established in 1960 to provide assistance for the same purposes as IBRD, but primarily in the poorer developing countries on terms that would bear less heavily on their balance of payments than IBRD loans. IDA's assistance is, therefore, concentrated on the very poor countries—mainly those with an annual per capital gross national product of less than \$520 (in 1975 dollars). More than 50 countries are eligible under this criterion.

Membership in IDA is open to all members of IBRD and 120 of them have joined as of June 30, 1978. The funds used by IDA, called credits to distinguish them from IBRD loans, come mostly in the form of subscriptions, general replenishments from its more industrialized and developed members, special contributions by its richer members, and transfers from the net earnings of IBRD. The terms of IDA credits, which are made to governments only, are 10-year grace periods, 50-year maturities, and no interest, but an annual service charge of 0.75% on the disbursed portion of each credit. Although

legally and financially distinct from IBRD, IDA is administered by the same staff.

Its standards for reviewing projects are IBRD's standards, its purpose is the same as the IBRD's and it lends to the same economic sectors for the same purpose as IBRD. Yet the sectorial composition of IBRD loans and IDA credits shows noteworthy differences. These differences result from the varying economic priorities of IBRD borrowers and IDA borrowers.

IFC

The International Finance Corporation was established in 1956. Its special purpose is to promote the growth of the private sector and to assist productive private enterprises in its less developed member countries where such enterprises can advance economic development. IFC is an affiliate of IBRD and, as such, shares with it common objectives and policies for improving the well-being of the peoples of less developed member countries.

Membership in IBRD is a prerequisite for membership in the IFC, which totals 108 countries as of June 30, 1978. Legally and financially, the IFC and IBRD are separate entities; the Corporation has its own operating and legal staff, but draws upon IBRD for administration and other services. It has the same President and many of the same Executive Directors.

IFC is not limited as to the form in which it may provide financing and its terms are flexible. Such financing normally consists of subscriptions to share capital or long-term loans without guarantee of repayment by governments, or both. It helps mobilize other capital and technical expertise for productive ventures that contribute to economic development and meet sound investment criteria. IFC also has a responsibility to promote such ventures by identifying and bringing together investment opportunities and qualified investors.

In addition, IFC seeks to encourage the flow of private capital in the countries it assists. To this end, it supports the establishment or expansion of local capital markets and financial institutions. It also offers technical assistance to member governments in support of their efforts to create an investment climate which will encourage productive and beneficial domestic and foreign investment.

IBRD/IDA/IFC lending

In Fiscal Year 1978 (ending June 30, 1978), IBRD together with its affiliates, IDA and IFC, made lending and investment commitments totaling US $8,749.1 million. One hundred and thirty-seven IBRD loans to 46 countries totaled US $6,097.7 million. Ninety-nine IDA credits to 42 countries amounted to US $2,313.0 million. The IFC made 41 investments amounting to US $338.4 million in 31 countries.

The combined IBRD and IDA lending amounted to US $8,410.7 million and was distributed by sectors as follows:

Sector	*US $ Million*	*% of Total*
Agricultural and rural development	3,269.7	38.9
Education	351.9	4.1
Energy	—	
Industrial development and finance	909.9	10.8
Industry	391.8	4.7
Nonproject	155.0	1.8

Population and nutrition	58.1	0.7
Power	1,146.2	13.6
Technical assistance	20.3	0.2
Telecommunications	221.1	2.6
Tourism	50.0	0.6
Transportation	1,092.9	13.0
Urban development	368.6	4.4
Water supply and sewage	375.2	4.5
	8,410.7	100.0

The Bank does not fix rigid sectorial priorities; it lends on the basis of the needs of a particular country or a particular region at a particular time. The relatively large amount lent for agriculture reflects the Bank's emphasis in recent years on agricultural development resulting in: (a) a larger proportion of total lending being donated to agriculture; (b) an increased share of agricultural lending going to the poorest countries; (c) a larger number of people benefitting from Bank-supported projects; and (d) projected increases in output by those farmers being assisted.

Assistance to small farmers to become more productive accounts for the major share of lending in this sector. The Bank considers that the small farmer is a critical element as a producer of foodgrains and other food products in many major food-deficit countries. Also, improved economic and social conditions are factors of prime importance in the effort to reduce population growth rates through lower birth rates. Massive rural poverty, sustained and spurred on by an increasing rural population, limited land resources, and inadequate supporting systems, is a continuing feature in most of the Bank's member countries. Bank programs aimed at the poverty problem include land and tenancy reform, credit, water supply systems, extension, training, and research.

Approximately ⅓ of the agricultural lending was for irrigation and drainage projects. The Bank normally finances from 30 to 50 percent of total project costs. Hence the loans represent a share of total project costs of more than double the figures shown. Other multi-lateral and bilateral sources contributed about US $3,000 million to total project costs, with the remainder being contributed by the borrowing countries. The typical Bank-financed irrigation or drainage project can include, in addition to the irrigation supply and distribution system, land preparation, extension and research services, rural water supply, electrification, schools, roads and health facilities, storage and marketing facilities, technical assistance, and training. Some of the other agricultural projects, such as agricultural credit, include substantial amounts for irrigation facilities such as tubewells, minor irrigation systems, and improved on-farm irrigation schemes.

Operating methods

Every project, irrespective of scope and size, financed by the Bank is considered in the light of a country's total needs, capabilities, and policies. Therefore, comprehensive studies are made of the economy of the country requesting assistance. The studies include detailed analyses of individual sectors and relationships between them, which throw light on the relative importance of alternative projects in achieving the country's development goals. Chiefly, on the basis of these studies, and after consultation with the government, a program of Bank operations in the country is drawn up for a five-year period with an updating annually. This program provides a framework for

concrete proposals for action to help the country implement agreed strategy of development. Each individual project is considered within this framework. Equally, project proposals arise out of the joint efforts of government and Bank staff in their search for solutions to common problems. The project is subjected to careful analyses, and a detailed agreement is worked out with the borrower before a loan or credit is approved.

Often, the Bank will recommend that consultants be hired to prepare detailed plans. Upon completion of the preparatory work, the Bank sends a staff mission to make a thorough appraisal of all aspects of the project. When agreement is reached on details of the proposed project and on financial requirements, a formal loan or credit agreement is negotiated. If this is satisfactory, the President presents the proposal to the Executive Directors, who represent all member countries, for their approval.

The approval of a loan does not end the Bank's involvement. In most cases, the borrower seeks bids, on the basis of international competition, for the goods and services required. The Bank releases money only as needed to meet verified expenditures on the project. Goods and services paid for by Bank loans or IDA credits may be obtained from any member country or Switzerland. The Bank pays in whatever currency is required, and the borrower repays in the currency used by the Bank.

Bank involvement continues throughout the life of the project. The borrower provides periodic progress reports, and Bank staff members visit the site from time to time, helping to anticipate and overcome difficulties and ensure that the project's intended benefits to the country are realized. This close supervision is facilitated by the fact that the borrowing country is a part owner of the Bank and shares in the control of its policies and operations. As a cooperative multinational institution, the object of the Bank is to see that each project is carried out at the least possible cost and that it makes its full contribution to the country's development.

Technical assistance

The provision of technical assistance, an integral part of the Bank's services to its developing member countries, has been expanding vigorously. Consultations take place between Bank staff and borrowers during project preparation and appraisal, and during country or sector reviews. Aside from this steady flow of technical information, the Bank assists its borrowers with the financing of feasibility studies, engineering, and resource surveys, and in helping build up institutions, in training, and the like.

Technical assistance was the exclusive purpose of one loan and two credits, for a total of US $20.3 million during fiscal year 1978. In addition, technical assistance components were included in 151 lending operations, for a total of US $230 million. Also, US $6.4 million of financing was provided by the Bank's Project Preparation Facility. The Facility makes temporary advances for studies and other forms of technical support; the borrower repays the advances by refinancing them through a Bank loan or an IDA credit for the project concerned as soon as it becomes effective. Other forms of assistance are provided on a reimbursable basis, or under equivalent compensatory arrangements, to oil-exporting countries that do not borrow from the Bank. In fiscal 1978, this kind of assistance in the amount of $33 million was directed to four countries.

For many years, the Bank has served as executing agency for preinvestment and technical assistance projects financed by the United Nations Development Programme (UNDP). A number of UNDP-financed, Bank-executed projects provide economic planning assistance. Typically, they call for small teams of planning advisers, support-

ing consultant services, and training programs for local counterpart staff. Of great significance to the developing countries is the fact that Bank-executed, UNDP-financed projects have an operation focus that very often leads to projects suitable for Bank financing, producing substantial investment follow-up.

The Bank maintains a staff college, the Economic Development Institute (EDI), to train officials of developing countries in the techniques of development. About 5,000 have attended EDI courses in Washington and overseas.

In addition, the Bank conducts a large, continuing program of research—both basic and applied — in virtually every aspect of development with which its members are concerned. At present, this program consists of more than 100 studies. Subjects include economic planning, agriculture and rural development, income distribution, international trade and finance, industry, labor-capital substitution, unemployment, urbanization, regional development, public utilities, transportation, financial institutions, and population and human resources.

International cooperation

While the Bank is large in relative terms, it is only one of many institutions—national and international, public and private—that provide financial and technical assistance to developing countries. In the public sphere alone, a dozen or more international institutions and 25 or 30 national agencies are involved in one way or another. With such a multiplicity of donors, lenders, and providers of technical assistance, close cooperation and some degree of coordination are essential. Methods employed by the Bank to achieve this vary widely, depending, among other factors, on the nature and scope of each institution's program.

The largest and oldest of the Cooperative Programs concerning agriculture is that between the Bank and the Food and Agriculture Organization of the United Nations. During fiscal year 1978 it staffed and carried out 177 missions in 55 countries. Loans for projects prepared by the Program represented about one-third of the year's lending for agriculture. Emphasis was on projects to benefit the rural poor and to promote close involvement of member countries in the formulation of projects.

Types of missions

There are usually four types of Bank missions involved in generating, financing, and implementing agricultural projects. The mission names are derived from the specific functions, i.e. identification, preparation, appraisal, and supervision.

Identification missions go to the field to make a preliminary determination of the nature and size of potential projects and the establishment of their prima-facie priority. Preparation missions provide advice to governments on project formulation and on the planning and execution of feasibility studies. Occasionally consultants may assist these types of missions. The feasibility study may be performed by the government or by consultants from external government or international agencies or by private consultants.

Appraisal missions evaluate projects on the basis of feasibility or equivalent studies and prepare a report that provides technical, economical, and financial justification of the proposed project for review by Bank management and for loan negotiations with the borrower. The appraisal report also serves as technical background and guide for project implementation. Typical types of consultants or Bank personnel used in irrigation project appraisals are: irrigation and drainage engineers, agriculturalists, agricultural economists, soil scientists, dam designers, hydrologists, and financial analysts.

Supervision missions are sent during project execution, usually twice a year, to review progress in the field. Normally such missions are small and exclusively comprised of Bank staff, but occasionally a need develops for augmenting regular staff or for special expertise to review an unusual field problem. The principal role of the supervision mission is to ascertain that the project is being executed and operated as set forth in the loan documents, but borrowers frequently seek Bank advice during these phases.

The Bank has spent about US $7 to US $8 million annually in recent years to engage the services of the individual consultants that provide special expertise on Bank missions. In some cases the Bank contracts with a company or an institution for the services of a specific individual expert, if this is the best way to obtain the services of the specialist. The consultant joins other mission members to review in the field the project under consideration, and upon return to headquarters is expected to prepare a complete report for his area of responsibility which can be incorporated into the mission report.

Examples of agricultural projects

Four examples of agricultural projects approved for IBRD and IDA assistance in Fiscal Year 1978 that involved water and land resource studies with participation of soil scientists are as follows:

Afghanistan. IDA—US $22 million. Some 12,000 farm families stand to benefit from a second Khanabad irrigation project which aims to develop agriculture by rehabilitating and extending existing irrigation and drainage schemes, extending agricultural credit to farmers, and by providing an efficient extension service. A malaria control program is included; so, too, is a feasibility study for a dam about 90 kilometers above the project area. Total cost: US $28.7 million.

Indonesia. IBRD—US $140 million. Some 189,000 farm families will benefit from a tenth irrigation project designed to rehabilitate, upgrade, and expand existing irrigation systems. Three construction components are included in the project, as are feasibility studies and detailed design work for a number of dams. Total cost: US $216 million.

Pakistan. IDA—US $70 million. Soil salinization will be halted and surface water deliveries increased by a project that includes canal remodeling, tubewell and drainage system construction, and credit and technical assistance to farmers living east of the Indus River in the Rahimyar Khan district of Punjab province. Agricultural production (mainly foodgrains, seed cotton, and oilseeds), employment, and incomes should all increase substantially. The United Kingdom is extending a US $16 million grant and the Kreditanstalt fur Wiederaufbau (KfW) a US $9.5 million credit to help meet project costs. Total cost: US $170 million.

Philippines. IBRD—US $150 million. To help finance the second stage development of a multi-purpose project on the Magat River, a loan will be made available to support a project consisting of all civil works for the main dam and appurtenant structures, reservoir area population resettlement, installed mechanical equipment, and the services of consultants. Total cost: US $346 million.

WATER AND LAND RESOURCE INVESTIGATIONS

The studies made in generating, appraising, and implementing agricultural projects usually address the present social, agronomic, and economic situation with respect to food and fiber production, marketing, consumption, and means and feasibility for modification. This includes water, land, human resources, and institutional development. Also changes in land use for increasing production and marketing to benefit farmers and other people are considered commensurate with promoting social well-being and improving or maintaining a favorable environment. For these studies, agriculture encompasses land resources, farm enterprises, and socioeconomic surveys. The agriculture study might cover a diversity of needs and conditions including both rainfed and irrigated lowland or upland agriculture under either private or government ownership and management.

Water and land resource studies serve an important role in the Bank's programs for agricultural and economic development. The investigations must integrate the activities of the several disciplines including water quality, plant science, hydrology, drainage, environmental science, engineering, sociology, geology, soil science, economics, and land and water use and management. Important in these studies is coordination of their independent activities into a meaningful framework of analyses. From the evaluations, alternative plans are developed to indicate required programming, operation, and development procedures conforming to area needs and controlling policies. Analysis is made of land use problems and opportunities associated with alternative plans, recognizing the natural and modified resource base; existing and potential land use patterns; zoning regulations; and general relationship to environmental, social, and economic aspects of the setting. All plans developed for achieving goals involve costs and benefits. In this regard, land use suitability classification, if properly structured and implemented, is a useful tool for identifying needs, establishing opportunities, and selecting lands for development.

The process is somewhat analogous to arranging for transportation at a travel office, eating at a large cafeteria or shopping at a large supermarket. The choices of items and combinations are numerous but somewhere along the line, someone has to pick up the tab and digest the bill. The final cost of investigations for planning is also very important. The borrower has to also bear these costs.

Land selection

Land use suitability classification is a key element in identifying, appraising, implementing, and maintaining agricultural developments. The Bank is in the process of establishing general requirements and guidelines for scope, kind, and amount of work for the various types of planning investigations and conditions encountered. The Bank is giving consideration to all known systems of soil survey and land classification, particularly those used by member governments. Further, the Bank is open to and solicits suggestions from any group or persons wishing to contribute ideas and recommendations. The Bank staff participates in the many consultations held for improving and advancing land selection criteria and procedures.

In many of the developing countries, the land resource studies, particularly those of feasibility grade, are made by consulting firms. The borrower, on its own or with the assistance of advisors or consultants, is expected to propose and undertake suitable soil survey and land classification procedures. They are encouraged to prepare tech-

niques drawn from their experience or that of others applicable to the particular conditions of the project under investigation. In exceptional cases at the request of the government, the Bank may propose to the consultant standards, methods, procedures and specifications for the conduct of a specific survey.

The system of land classification should be unifying and universally applicable to either diversified cropping or wetland rice production for all situations and ranges in water supply and control including rainfed agriculture, irrigated agriculture, water regulation in food plains, and reclamation of marshlands and tidelands (Peters, 1975). Accordingly, the surveys must cope with differences in the source, quality, and control of water. The economics with respect to productivity, land development, flooding, and drainage are highly relevant.

A feasibility grade land resource survey for irrigation development should establish the extent and degree of suitability of lands for sustained profitable irrigated agriculture. It should deal with the question of whether or not the project is worthy of construction. It should be supported with special studies in the fields of water quality, soils, topography, drainage, economics, and land use in selecting lands for irrigation. The compilation of findings and presentation of results should be accomplished by narrative reports and land classification maps and pertinent field and laboratory data. The report should cover basic data, premises, description of methods of study, discussion of results, and pertinent conclusions and recommendations relating to investment feasibility.

Bank experience in working on many projects in many countries having diverse policies, goals, and conditions have brought out some definite requirements. A major requirement is the necessity to fully explore and consider the controlling policies in structuring and implementing a land classification for local application. To be useful and effective a survey must avoid a rigid or fixed procedure. A survey should be structured to effectively serve the purpose of the investigation at hand and be site-specific in scope and application, i.e. it must be fitted to the specific environmental setting including economic, social, physical, and legal patterns existing in the area. It is extremely important that a survey be accomplished at a cost that the borrower can afford to pay and be acceptable in relation to the investment foreseen for ensuring development activities. It is also important that the survey be completed within a time frame that will facilitate planning.

So often, it is not understood that requirements of a land classification set up primarily to guide on-farm land development and settlement following initial project construction can be expected to differ from one aimed at determining engineering, economic, and agronomic feasibility in planning for a project. Both the scope and degree of detail can differ markedly.

Methodology between countries may vary according to whether the government expects the farmer or landowner to pay for all development costs or if the government does all of the on-farm development with no direct cost to the farmer. The matter of handling land development costs should be resolved prior to initiating a survey.

Land classification surveys or interpretations of soil surveys should express the land-water-crop and economic interactions expected to prevail after resource and management modification (Maletic and Hutchings, 1967). This involves identifying and evaluating changes anticipated to result from development or reclamation and management. The interactions should be expressed in terms of a suitable economic parameter reflecting productivity, preferably net farm income.

Most land factors, including soil depth, are changeable at a cost. Typical changeable factors include salinity, sodicity, titratable acidity and exchangeable aluminum, depths to water table, relief, brush and tree cover, rock cover, drainage, and flood hazard. Particle-size distribution or texture of subsoils and substrata occurring at depths not disturbed by tillage and landforming is about the only factor that may not be altered.

Some of the changes can be brought about by modifying water control measures and management. These include variation in depths to water tables and associated soil moisture, salinity, and aeration conditions affecting tillage and crop growth. Other examples are modification of slope and microrelief by landforming; and alteration of soil profile characteristics by deep plowing, chiseling, or addition of amendments. Soil texture may be modified by sediment in water entering the soil.

The manner and magnitude of water control can effectively serve to regulate salt effect on lands, crops, social and economic conditions, and the environment. The concentration and composition of salts in the soil solution and associated exchangeable ion status on soils can be influenced by numerous factors including the composition of water applied, the rate of water application and leaching, dissolution and precipitation of soil solution constituents, and the rate and amount of drainage. Flooding of soil, as practiced under rice cultivation, sets into motion a series of physical, microbiological, and chemical processes which influence crop growth (Ponnamperuma, 1965). Soil acidity usually decreases upon flooding.

Whether given characteristics will be changed usually depends upon economic considerations. The survey must deal with two aspects of this principle. Can the change be accomplished, and what degree of change is economically feasible? This is largely dependent on the climatic and economic setting of the project. For example, a large investment may be made to reclaim a saline, sodic or acid soil which after improvement will yield a new farm income of US $500 per hectare. In another setting, where net income after improvement would only be US $75 per hectare, the soil having similar conditions might be regarded as non-reclaimable. In the latter case, it may be infeasible to make the change.

The establishment of the minimum land quality of maximum development cost that should comprise arable land or the service area is requisite in implementing the basic and most important decision in land selection, which is the separation of lands which are suitable for development from those which are not. In doing this, recognition should be given to the fact that in fitting economics into a land selection there is a limit on the attainable precision. Thus, management levels, yield estimates, and related factors can be expected to vary in a particular area and with time. The imprecision involved needs to be accepted; otherwise, the economic principles guiding choice of land can be rather useless and the alternative would be to use arbitrary physical limits for land class determination. This usually results in poor planning for the development of a resource. When confronted with decisions to build or not build, to serve this area and not the other, and to properly size facilities, someone needs to make a firm interpretation. Much of the data can be collected when surveys are approached as interdisciplinary exercises.

In investigating lands consisting of highly leached and weathered soils, a strong soil characterization program should be conducted. The chemical status of such soils needs to be carefully evaluated along with observable characteristics in making sound selections of arable land. The problems confronted with these soils are usually fertility-related chemical characteristics requiring special appraisal. These include

degree of weathering of the clay minerals; soil acidity; charge status both negative and positive and associated ion population; soluble and exchangeable iron, aluminum, and manganese; base saturation of cation exchange capacity at relevant pH values; and nutrient status of the soils. Such characterizations identify infertile soils having limited suitability for continuous crop production because of the need for high inputs of both money and management. On the other soils they indicate the type and level of production inputs required to attain specified yield levels of particular crops. Of course, other soil characteristics such as texture, structure, depth, water-holding capacity, infiltration rate, permeability, and claypans are evaluated as are water quality, climate, topography, and drainage conditions. Salinity reclamation and control can be a factor in high rainfall areas including the topics.

It is imperative that irrigation suitability surveys be supported by laboratory and field testing and evaluation that will assure a definitive diagnosis of soil salinity and sodicity under present (without project) conditions and prognosis of these soil properties associated with agronomic response and economic significance under future (with project) conditions. This necessitates adapting and implementing meaningful procedures and studying the irrigation experience on similar lands. It is essential that land classification surveys and the drainage investigations be fully integrated and coordinated.

Drainage investigations

Both land drainability and drainage requirements are needed in water and land projects. Kinds of information needed include: the capacity of the soils, subsoils, and substrata to transmit water; amount, source, movement and chemical characteristics of the water that must be transmitted; and available hydraulic gradients, both natural and those that can be induced by engineering works (USDI Bureau of Reclamation, 1978). The studies usually should include evaluation of hydrology, geology, meteorology, particularly effective precipitation, topography, soils, and present and anticipated irrigation practices and cropping patterns; conduct of field measurements for hydraulic conductivity, and design of any required drainage.

Water suitability

The suitability of a water for irrigation should be determined by integrating the land and water factors and identifying those lands that will respond feasibly to a water supply of a given quality. Water quality standards or ratings per se may not be appropriate in appraising the usability of water for irrigation. Criteria of water suitability vary with the intended use of the water (Bower, 1974). As has been stated by Fireman (1960): "Its usability depends on what can be done with the water if applied to a given soil under a particular set of circumstances. The successful long-term use of any irrigation water depends more on rainfall leaching, irrigation water management, salt tolerance of crops, and soil management practices than upon water quality itself." Thus, the suitability of an irrigation water must be evaluated based on the specific conditions under which it will be used, including crops to be grown, soil properties, irrigation management, cultural practices, climatic conditions, and especially leaching fraction (Rhoades and Merrill, 1976).

Present land use

Information is usually needed on present land use in a proposed project and within impacted areas associated with the project. The land use categories to be mapped and who does the mapping need to be established in consultation with planners.

Laboratory support

In addition to field measurements for water and salt movement and retention in soils, a certain amount of characterization by laboratory methods is required in support of land selection for water and land resource development. The objective of characterizing soil is to support judgment in estimating land development reclamation potential. The laboratory analyses should be performed on an action program basis and serve a practical purpose.

A system of screenable soil characterization that is sequential in analytical approach should be implemented. This involves applying logical deductive reasoning in providing for specific useful data. These data are generated and evaluated sequentially as required to support decisions to soil-specific problems directly and to determine additional properties. This maximizes use of data for problem quantification and degree of remedial measures necessary. It should be used to study problems and derive solutions rather than using standardized routine tests. It follows that application of this technique optimizes effort and reduces expenses (personal communication, L. L. Resler, USDI Bureau of Reclamation, Denver, CO).

There is a tendency among many laboratory activities to "over test"; i.e. perform too many or unnecessary tests on certain soils at the expense of not performing essential or critical testing on particular samples. Also, some laboratory activities tend to emphasize comprehensive analyses of samples from master sites and neglect selection, sequence, and quality control in mass testing performed on a screenable basis. The latter-type testing is frequently handled as routine work utilizing the least dependable personnel and considered not worthy of competent and close supervision. Thus, too often the screenable laboratory testing becomes a liability rather than an asset in supporting surveys. Because the screenable testing represents coverage of areas involving a high sampling density, it serves as an extremely important input into land categorization. Therefore, it should be administered for performance with respect to both quality and quantity commensurate with the goals and objectives of the investigations.

To effectively support field appraisals, all laboratory work should be closely coordinated with field work. Laboratory studies should be preceded by or made concurrently with field studies. The number and type of studies should be determined by area conditions—particularly variability, the controlling survey specifications, and needs. There should be a joint plan between field and laboratory investigations prior to taking of samples (Kellogg, 1962).

In implementing screenable testing, relevant evaluation parameters need to be established and measured and their interrelationships understood. In all investigational programs, care should be taken to not create a false impression of technical excellence by generating superfluous analytical data. Screenable testing tends to avoid this, provided it is properly set up, implemented, and results interpreted. Of course this type of characterization program should not preclude testing on the conventional "complete analysis" basis of samples from master sites.

Usefulness of soil surveys

Soil surveys, particularly genetic and morphological classifications (taxonomic soil surveys) are useful in planning for water and land resource development. Invariably, there have been limitations involved with such surveys and interpretations that could be made in selecting lands for irrigation development for diversified cropping. The limitations along with mutual support possible in substituting soil surveys for land classifications become understandable through recognizing the unique differences in relation to specific needs for varied applications. That soil surveys may not fully satisfy requirements should not be taken as a case for indictment, drastic change, or abandonment. On the contrary, soil surveys should be used to the fullest extent possible.

In addressing the subject and trying to develop understanding of the subject over a period of many years in several countries, it is helpful to recognize the numerous types of soil surveys conducted in the world and reasons for different approaches along with the many specific requirements for varied applications involving a wide range in climatic and economic settings. Often, it is not possible when making a soil survey to foresee all future applications. Further, the demands of a soil survey even though anticipated in advance usually preclude structuring a system that will serve all purposes. It is frequently difficult to obtain participation of the requisite disciplines especially when planning for a specific use which may not materialize immediately or for several years. The cost of investigations can be a constraint on the amount of data collection. Thus, limitations in using soil surveys are inevitable.

Soil characteristics which are important in a genetic or morphological classification are normally by no means the only factors that are of primary importance in land classification for certain uses, particularly irrigation. Soils are an important aspect of lands but may be overshadowed by many factors including economic circumstances, agricultural technology, resourcefulness of people, climate, topography, and drainage. It follows that the factors other than soil have to also be taken into account, kept in perspective, and integrated. Data collection and land classification for irrigation planning need to be approached as an interdisciplinary exercise, wherein contributions to the land classification are made by drainage engineers, economists, and hydrologists. Unsatisfactory land classification surveys can arise if a soil scientist works alone and concentrates almost solely on the soil mantle. Most soil survey organizations even in the developed countries, being vertical rather than horizontal with respect to management, do not accommodate participation of other specialists.

There can also be other problems in implementing soil surveys and making interpretations for uses such as irrigated agriculture. Many workers trained in mapping natural bodies have great difficulty in initial attempts to adopt and adapt to economic land classification. The difficulty seems to be in conceptualizing the landscape under the conditions expected to prevail under the new land use regime through economic reasoning and installation of control structures. Another difficulty concerns notions that boundaries of natural bodies will coincide with class boundaries, ranking land for use suitability. This rarely occurs because kinds of soil having natural boundaries are commonly found in contrasting economic environment or vice versa. The location, size of tract, and other economic characteristics of land are highly significant in land classification.

It can be very difficult to rely upon natural body mapping, as commonly made, for classifying a given area, particularly on complex and problem lands consisting of soils and substrata requiring extensive and intensive field and laboratory characterization.

Although logical procedures can be advanced for accomplishing the required integration, experience has shown that the procedures necessary for a land classifier to establish class boundaries related to natural body mapping units can be nearly as time-consuming as the conduct of a basic land classification without benefit of a soil survey. This is not to imply that soil surveys are not useful. Natural soil bodies, because of their information content, can provide much essential information, including bases for deriving predictions.

Principal deficiencies of most soil surveys in planning for irrigation development are insufficient depth of soil characterization, simulation of soil moisture retention and movement in the laboratory without field confirmation, inadequate soil drainability and land drainage appraisals, and lack of definitive laboratory characterizations for soil sodicity (alkali), beneficial gypsum, and effective soil acidity. Soil profile examination to the depth of 1–2 meters usually will not suffice in appraising economics of drainage. Soil profile examination should include depths to 3 meters and some of these need to be extended to greater depths.

There is no theoretical reason why soil surveys, if properly structured and adequately supplemented, will not meet needs in planning for water and land resource development for alternative uses. Many workers have given thought to this and some have advanced suitable procedures (largely unpublished) for accomplishing this. Often, it is not practical nor technically and economically expedient to go this route. Also, in areas having no previous soil survey and where a decision has been made to embark upon detailed investigations involving extensive coverage and intensive study, the soil survey can be the product of the land classification rather than vice versa.

Increasing and expanding the role of soil surveyors

Soil survey organizations and soil surveyors worldwide are dedicated to having a specialized and professional product in soil inventory information and interpretive evaluations and classifications that will be extremely valuable and relevant to needs in water and resource development. Many workers, primarily in the more developed countries, are generally contending that their product is neither adequately understood nor used by planners and decision makers. Some are gravely concerned and express frustration at having an outstandingly useful product but not being able to attract logical customers and selling it to them. They are seeking ways and means by various methods and forums as evidenced by this Workshop to bridge the gap whereby there might be generated an increased awareness for and transfer and use of soil inventory information.

Certainly and unfortunately, there is validity and justification in some of the contentions. However, in certain circles and too many instances, there seems to be too much crying and only posing a dilemma. Although this may serve to get needed attention, it, in being rather negative, is not likely to facilitate changing the situation. A more objective and positive approach along with more consultation and cooperation with users is needed if the problem is to be identified and solved.

It should not be the sole prerogative of the soil surveyor to determine the nature of the product and what should be marketed. The user (including farmers, planners, taxpayers, financing agencies, governments, and others) of soil inventory information and interpretations that can be made also have an interest and stake in applications and have the right to be in on decisions on what can be used and is to be bought for specific needs within institutional, legal, time, and financial constraints. Therefore, the soil

surveyor should seek out the users and solicit views on needs and jointly develop the product. It is essential that the process be a two-way street with communications and travel going in both directions.

Soil scientists represent a basic discipline vital to planning but do not possess a monopoly on involvement and knowledge in the collection of land resource information, interpretations, and integration in planning for irrigation. As previously stated, other basic and cooperating groups include agronomy, engineering, hydrology, geomorphology, environmental science, economics, law, and sociology. The decision-making discipline is political science. The soil surveyor or land classifier, after consultation with the other disciplines in developing survey specifications or guidelines for a specific setting, can accomplish most of the mapping, delineation, and classification of areas susceptible to sustained agriculture, i.e., arable lands as guided by farm production economics. This would include evaluation and mapping of land productivity, land development costs, land drainability, and interaction of water quality on soils and crops for ranges of leaching fraction. The selection of those lands classed arable to be actually served by project facilities is guided by economics of plan formulation with the other disciplines, particularly engineering, economics, and law, having major roles but with the decision maker doing the final selection. This selection usually reflects the desire to promote socio-economic development and achieve a more equitable distribution of wealth.

Irrigation engineers, drainage specialists, and water utilization hydrologists are knowledgeable as a result of both training and experience in the importance, methods of measurement, and applications of moisture retention and movement in soils, e.g. infiltration rate, hydraulic conductivity, hydraulic head, hydraulic gradient, water table location and conditions, moisture retention at various tensions, and so-called field capacity. It is usually the soils report rather than the engineering report that fails to provide a satisfactory confirmation of a perched water table and distinguish between q and k in Darcy's law. The dam engineers and drainage specialists are usually most proficient in installing piezometers to establish the occurrence of artesian pressures and characteristics of moisture movement in slowly permeable earth material.

Enlisted personnel of many navies readily adapt to testing the quality of distilled water for usability in boilers to produce steam. This involves appraising the intensity of acidity or alkalinity, i.e. pH, salinity, and total hardness, by rapid but quantitative measurements respectively for electromotive force, electrical conductivity, and calcium plus magnesium by versenate titration. The same type of analysis, using a kit, can be used to rapidly characterize soil in the field with respect to both salinity and sodicity (alkali). In the latter regard, reliable values can be obtained for the estimated sodium adsorption ratio, gypsum requirement, and residual gypsum. These characterizations in combination with other innovations are more useful in the diagnosis and prognosis of soil sodicity than only measuring for exchangeable sodium in milliequivalents per 100 grams and exchangeable sodium percentage by conventional procedures, which are time-consuming, and using sophisticated laboratory equipment by flame photometry and atomic adsorption spectrophotometry. The procedures for rapid field testing were developed by the USDA Salinity Laboratory about 25 years ago and kits have been on the market as long. Yet, few laboratory and field soil scientists have availed themselves of this opportunity to become more effective and efficient.

The requisite level of land productivity or permissible land development cost for a specific project setting as perceived by a soil surveyor or land classifier may differ from

that of an economist even if the interrelationship of their work is mutually understood and there has been close cooperation. Just as the pedologist has his tools, diagnostic criteria, and jargon, the economist also has tools and jargon but that of the latter is more standardized and universal and can be translated into and comprehended in most languages including English. Attempts at translating the Greek nomenclature of the American system of soil taxonomy into English have not been too successful.

To serve the user of soil survey information in an increased and expanded role by working more effectively with other disciplines, most soil surveyors need to become more cognizant of the role, tools, and terms of economists. Land selection for development and increasing productivity is influenced by economic evaluation in several ways. Some of the terms that need to be understood are accounting price, adjustment value, benefit-cost ratio, book value, consumptive rate of interest, discount rate, economic rate of return, elasticity of the marginal utility of income, externality, financial rate of return, least cost analysis, opportunity cost of capital, shadow exchange rate, and world market price.

Probably the least understood and most scoffed at is the role of lawyers in land selection for irrigation. The delineation of irrigable areas and water allocations and impacts must conform to the laws of a country and international law. Water lawyers and courts are the final authority on what lands can be legally served under existing laws with irrigation and drainage facilities. Some are even knowledgeable in irrigation suitability land classification.

In the United States, the legal profession in representing the principal user, i.e. the people especially farmers, wrote, through Congress, the paramount legislation comprising the 1924 Fact Finder's Act. This law established the type of land classification required for all Federal Reclamation Projects and defined the land classes in terms of an economic parameter, i.e., net farm income and payment capacity. This led to development by planners, economists, lawyers, engineers, hydrologists and soil scientists of the USDI Bureau of Reclamation system of land classification for systematically obtaining and interpreting resource information. Other countries do not have the specific law but it can be expected that policies and executive orders will be in accordance with legal constraints, particularly in the many countries having Anglo-Saxon law.

The United Nations Food and Agriculture Organization (FAO), Rome has been developing, over a period of about 10 years, *A Framework of Land Evaluation*. This is being developed through international cooperation and stems from consultations with the World Bank which has always insisted (as recognized by FAO) that soil surveys as traditionally made did not meet needs in assessing agricultural potential of the world's land resources. In this regard, the inadequacy of soil surveys in serving needs of users and some of the reasons why are eloquently presented by Dudal (1978a). In the *Framework*, land is being defined as the physical environment including soils, climate, relief, hydrology, and vegetation. The evaluations are made for specific uses with respect to specific inputs and with interdisciplinary participation of crop ecologists, agronomists, climatologists, and economists in addition to pedologists. While the evaluations of lands have been initially based on physical attributes, developers of the framework recognize that economic and social factors need to be taken into account (Dudal, 1978b). FAO is presently exploring requirements with respect to both social and economic aspects and giving consideration to evaluation of these factors in the *Framework*.

The importance of having a system of land classification that will utilize and integrate the contributions of all requisite disciplines, particularly economics, cannot be overemphasized. Sound planning cannot proceed on the basis of missing links.

Also, the contributions from each discipline into the classification survey need to be coordinated. As Kellogg stated about 30 years ago, "It seems to me that many groups of specialists have certain contributions to make a general system of land classification. They must be mindful of their limitations and contributions of others. Each must organize his data that they may be coordinated with the data of others. To do this, each must understand the general problem and the objective of the land classification clearly, which is the only basis for successful coordination" (Kellogg, 1940).

In advocating a system of classification for a specific use, the soil surveyor should dig in and think how the use differs from and is better than others, and to what extent the user will benefit by endorsing it. Soil surveyors can be assured that the users of soil inventory information are hungry for a good product and want to know as much as possible about the product, how it is produced, and the people and organization who produce it. Hopefully, participation by the Bank at this workshop will be construed as confirming this view and as an effort by a major user of soil resource information to seek this type of information and to exchange views.

CONCLUSION

Soil surveyors have made contributions to water and land resource development and will continue to do so in the future. The Bank would like to be kept advised of findings and advances and looks forward to sharing experiences and views on this important work. The opportunity to participate in the workshop is appreciated.

LITERATURE CITED

BOWER, C. A. 1974. Salinity of drainage water. p 471–486. *In* Jan van Schilfgaarde, et al. (ed.) Drainage for agriculture. American Society of Agronomy, Madison, WI, USA.

DUDAL, R. 1978a. Adequacy of soil surveys and soil classification for practical application in developing countries. Paper presented to the Seminar of Operational Implications of Agro-technology Transfer Research. ICRISAT, Hyderabad, India, 23–27 October 1978.

DUDAL, R. 1978b. Land resources for agricultural development. International Society of Soil Science, 11th Congress, Volume 2-Plenary Papers.

FIREMAN, M. 1960. Quality of water for irrigation. University of California Extension Service, Davis, CA.

KELLOGG, C. E. 1940. Theory of land classification. Missouri Agricultural Experiment Station. Bulletin 421, The Classification of Land.

KELLOGG, C. E. 1962. The place of the laboratory in soil classification and interpretation. U. S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

MALETIC, J. T., and T. B. HUTCHINS. 1967. Selection and classification of irrigable lands. p. 125–173. *In* R. M. Hagan, et al. (ed.) Irrigation of agricultural lands. American Society of Agronomy, Madison, WI, USA.

PETERS, W. B. 1975. Economic land classification for the prevention and reclamation of salt-affected lands. Paper prepared for the Expert Consultation on Prognosis of Salt-Affected Soils, The United Nations Food and Agriculture Organization, June 3–6, 1975, Rome, Italy.

PONNAMPERUMA, F. N. 1965. Dynamic aspects of flooded soils and the nutrition of the rice plant. p. 295–328. *In* Proceedings of a Symposium—The Mineral Nutrition of the Rice Plant held at the International Rice Research Institute, Los Baños, Philippines, February 1964. Johns Hopkins Press, Baltimore, MD.

RHOADES, J. P., and S. D. MERRILL. 1976. Assessing the suitability of water for irrigation: Theoretical and empirical approaches. p. 69–109. *In* Prognosis of salinity and alkalinity. FAO Soils Bull. No. 31. FAO, Rome.

USDI BUREAU OF RECLAMATION. 1978. Drainage manual. U.S. Government Printing Office, Washington, D.C.

The Comprehensive Resource Inventory and Evaluation System

A Caribbean Experience

John W. Putman

The creation of a natural resource base assessment for national planning poses formidable problems. The problems are even more severe in the developing world. The time, budgetary support, and professional expertise necessary to develop these data are extremely scarce. Moreover, developing countries have an immediate need to plan and monitor agricultural resource management and development programs. Hence, soil scientists and planners must draw upon their scientific backgrounds to provide initial resource assessments for national-level planning from data that do exist in developing countries.

CRIES OBJECTIVES

The Comprehensive Resource Inventory and Evaluation System (CRIES) Study was initiated two years ago in the Dominican Republic, Nicaragua, and Costa Rica to explore methods for adapting U.S. procedures to the agricultural resource planning problems of developing countries. The study involves the Agency for International Development (AID), three agencies of the United States Department of Agriculture [Economics, Statistics, and Cooperative Service (ESCS), Soil Conservation Service (SCS), and Science and Education Administration (SEA)], and two Departments of Michigan State University (Agricultural Economics and Resource Development). The overall goals of the study are to transfer to the participating countries the capacity to analyze agricultural resource problems. Specific objectives are:

1. To assist host countries in incorporating the system and developing a data base and analytical capacity to explore the extent, quality and use options of agricultural resources and estimate the impact of alternative resource policies and procedures.
2. To expand the number and enhance the capability of host country planning personnel to maintain, refine, and use the information base and analytical procedures on a sustained basis.

3. To develop a coordinated resource classification system and analytical framework adaptable to many countries and capable of accumulating, storing, and transferring consistent information among countries.

Objective 3 is the focus of my remarks today. Before getting to the specifics, however, let me elaborate on some longer-range goals that underlie the design of the study.

Long-range planning of U.S. agriculture and forecasting of domestic production needs and prices are heavily dependent upon world markets and the United States' share in those markets. Further export markets will be determined, in part, by the ability of food- and fiber-deficit countries to increase their own production. Hence, the accumulation of consistent estimates of country and multicountry production capability and relative supply costs is of great importance to the USDA in assessing comparative advantage amoung countries and prospects for world food supplies.

As a consequence, project development has stressed the need for a system which can be universally applied to support long-range departmental objectives of developing information systems with consistent linkages among systems. Moreover, we are concerned with a sound basis for agrotechnology transfer. Beyond the traditional use of technology transfer, we see it as a way to extend information and improve forecasts.

CONCEPTUAL NEEDS

Figure 1 depicts the major components needed for a resource assessment. The system poses a heavy burden on planners in developing countries. Getting empirical data to fill every cell is impossible. Hence, the immediate objective is to conceptualize the needed data in appropriate form and fill the "first generation" data set with the most objective and informed judgments possible. Even judgmental data, when arranged in a logical, systematic system, can improve decisions. More importantly, the system provides the structure and form for future data development efforts. If properly designed and maintained, the system can be very useful while it is being refined and can create great efficiency in prioritizing future data gathering efforts.

As in any resource assessment, the "cornerstone" of the system is the scheme used to identify and stratify land resources into functional planning units. The resource classification scheme provides the means for storing and using all of the many data in the system. The resource units must be sufficiently homogeneous to be characterized by unique estimates of all other variables—land use, crop adaptability and productivity, management practices, treatment needs, and development potential. The resource units must also be geographically located for computational purposes and analysis with other data sets from other sources and other geographic configurations. Finally, the system must be controlled to manageable data proportions.

CRIES AGRICULTURAL RESOURCE INVENTORY SYSTEM

The basic conceptual units for the CRIES Agricultural Resource Inventory System (ARIS) are the resource planning unit (RPU) and the production potential area (PPA). RPUs and PPAs are defined as follows:

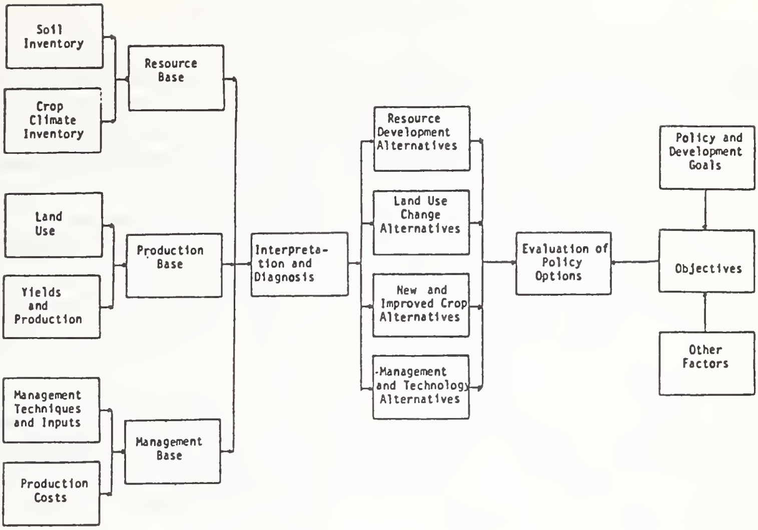

Figure 1. Flowchart depicting major components and their interrelationship in the CRIES system.

Resource planning unit

An RPU is a geographically delineated unit of land (not necessarily contiguous), that is relatively uniform with respect to the land forms, kinds and patterns of soil bodies, climates, water resources, potential vegetation, and general types of agriculture.

Production potential areas

A PPA is an aggregate of individual soil bodies and associated microclimates within an RPU which is sufficiently homogeneous with respect to plant adaptability, potential, productivity, and management requirements to be reliably depicted by unique agronomic and economic estimates for national and regional analysis and planning.

The concepts and definitions of RPUs and PPAs reflect the relationships among soils, climate, and plant growth. They are based upon two underlying taxonomies—soils and crop climate. The soil resources are stratified according to USDA's *Soil Taxonomy* (Soil Survey Staff, 1975). I won't attempt any explanation of soil taxonomy to this group. The crop climate taxonomy is a classification system being developed by the Ecosystematics Program, Science and Education Administration [formerly Agricultural Research Service (ARS)], USDA, entitled, "Crop Climate Taxonomy" (Science and Education Administration, USDA, 1978). Intended as a universal system, it can accommodate inputs and interpretations from the many climatic vegetative systems used in the various parts of the world. Three levels of categories are described in this hierarchical system—primary, secondary, and tertiary. Criteria for the system are based upon annual temperature and rainfall and seasonality of precipitation.

DERIVATION OF RPUS and PPAs

Since RPUs generally depict physiographic areas, they can be mapped rather quickly and efficiently in areas where soil information is scarce and scattered. They have discernible natural features and, when combined with crop climate zones, are describable with respect to climate. They provide the cartographic reference for analytical purposes and serve as reference points for field technicians.

To interpret an RPU for plant adaptability, productivity, and management choices, the soil bodies and associated microclimates within an RPU must be considered in greater detail. Hence, the major soil bodies and associated microclimates are identified and described as PPAs. They are estimated with respect to their extent and patterns within an RPU. The PPA descriptions provide the basis for determining coefficients used in our system of resource assessment and analysis.

PPAs are taxonomically definable and could be mapped. Mapping them, while very desirable, is unnecessary for national planning and policy analysis. Policy choices and priorities can be based upon the general knowledge of the extent, distribution, and patterns of the PPA within the map units. Scarce manpower and funds to generate the soil detail for implementation can be more efficiently programmed after national policies and priorities are established.

CORRESPONDING LEVELS OF TAXONOMIES

The *Soil Taxonomy* and "Crop Climate Taxonomy" must be used at appropriate corresponding levels in the taxonomies to provide meaningful analytical units for agricultural planning and production potential assessment. We are currently describing PPAs at the associations of phases of subgroup level of *Soil Taxonomy* and at the secondary level of "Crop Climate Taxonomy."

Since both systems are hierarchical, we see other possibilities for linking the various data and analytical levels. Over time, research data, field trials, and other information from projects such as the "Benchmark Soil Project" can be accumulated at the series and family level and used to improve the knowledge in the appropriate phases of subgroup categories we use for national analysis. Similarly, global studies aggregated to higher levels of taxonomic detail can draw on such material for input. We hope to use *Soil Taxonomy* much as a file outline to accumulate data and eventually make it more accessible to users. Such a system, however, must be carefully safeguarded and never used without proper scientific interpretation.

GEOGRAPHIC DATA FILE

Masses of data are of little use to planners and analysts without some means to manipulate them. CRIES has developed an Agriculture Resource Information System (ARIS) to store, retrieve, and manipulate mapped resource data. ARIS is composed of two parts: a process to digitize the various maps and a computer mapping system to analyze, summarize, and display the data.

A grid referencing system based upon Universal Trans Mercator (UTM) coordinates is used to assign each km^2 a unique cell address. As succeeding maps are digitized, map

parameters for each map are recorded and stored for each grid cell. Our system emphasizes the use of manual procedures in the coding process. We have done this deliberately to develop technology that can be easily transferred and installed in developing countries without large investments in equipment. The system is quick, efficient, and dependable. Hardware requirements are minimal. All that is required is a keypunch machine, a small computer, and tape or disc storage. We are investigating putting the system on a "mini" computer.

The computer system consists of a series of program phases to perform specific operations on data. Outputs such as cross tabulations and computer maps are shown in Figures 2 and 3.

C R O S S   T A B U L A T I O N   O F
LAND USE BY SOIL TYPE

LAND USE (COUNT / ROW PCT / COL PCT / TOT PCT)	SOIL TYPE 1	2	3	4	ROW TOTAL
1	144. 31.4 40.2 6.2	230. 50.2 19.3 10.0	48. 10.5 8.4 2.1	36. 7.9 19.8 1.6	458. 100.0 19.9 19.9
2	83. 11.3 23.2 3.6	530. 72.4 44.5 23.0	79. 10.8 13.8 3.4	40. 5.5 22.0 1.7	732. 100.0 31.8 31.8
3	78. 9.4 21.8 3.4	398. 48.0 33.4 17.3	323. 38.9 56.3 14.0	31. 3.7 17.0 1.3	830. 100.0 36.0 36.0
4	53. 18.7 14.8 2.3	32. 11.3 2.7 1.4	124. 43.7 21.6 5.4	75. 26.4 41.2 3.6	284. 100.0 12.3 12.3
COLUMN TOTAL	358.	1190.	574.	182.	2304.
PCT. TOTAL	15.5	51.7	24.9	7.9	100.

Figure 2. Sample of a cross-tabulation table produced by the CROSSTABS phase.

Figure 3. Printer map depicting irrigated areas and areas of potential irrigation in the Dominican Republic.

MERGING RESOURCE DATA AND ECONOMIC DATA

In nearly every planning situation, the conversation of economic and demographic data summarized by political boundaries to physiographic planning units plagues planners and analysts. This is particularly true of general land use and cropping information. Many statistical and judgmental processes have been developed and used in the U.S. Most involve the disaggregation of political boundary data to physiographic subunits through the use of data sets such as the Conservation Needs Inventory (CNI) and informed judgment. The process creates estimates of crop use, etc. by soils and other physiographic boundaries that are controlled within known, published totals.

These problems are intensified in the developing world. Reliable country totals of crop hectarage and production are difficult to obtain and subcountry values are even less reliable. Moreover, the data and statistics that are available are usually tabulated

on a crop harvested basis. With the occurrence of multiple and sequential cropping in the tropics, the crop use to a unit of available cropland ratio usually exceeds one but is difficult to precisely quantify from existing secondary sources.

CRIES' analysts are experimenting with several processes to develop estimates of land use and cropping patterns by RPUs. We are developing a process to interpret LANDSAT imagery visually to estimate general land use, cover types, and farming densities. We do this by identifying and describing typical types of agricultural use and/or cover in test sites. The gray tone levels of the test sites are measured and the readings used as inputs to a computer program which assigns a color to each band and sensitivity ranges for a color diazo mylar. After field checking, the resulting generalized use/cover map is digitized and added to ARIS.

We have had little success in identifying crops or crop types except in special situations. General land use information is far from ideal, but it does give us some basis for allocating individual crops to RPUs. Also, by using ARIS to overlay RPUs, political boundaries, and land use maps in the computer, we can get exact measurements of these land use categories by RPUs and provinces.

A second process we are working with is the incorporation of area-frame samples into the data process. AID has a large program with ESCS, Statistics [formerly the Statistical Reporting Service (SRS)] to establish area-frame samples in the developing world. The process is similar to the program in the U. S. which generates crop forecasts and annual acreage and production statistics. The procedure is very promising. ESCS, Statistics is working with digitally interpreted LANDSAT data and field enumeration of sample sites to expand the samples to regional and country totals with greater accuracy. We have a cooperative project in the Dominican Republic to adapt the sample-frame process to our data needs. We have located the sample plots in ARIS and will explore the use of sample data to develop crop allocators by RPU. Since the sample is designed to estimate regional and national totals, the samples by RPU will be less reliable than desirable but still very useful.

A special farm survey is planned in the Dominican Republic in 1979 to obtain detailed farm characteristics, production costs, and income data from these same samples. We are hoping we can add questions on land use by crops, combinations of crops, and sequences of crops to provide a better basis for allocating crops to RPU.

Since PPAs are unmapped, we have few options other than using the judgment of scientists in soils and agronomy and /or field technicians to initially allocate RPU totals to the individual PPAs. This is not different from the U.S. data situation where very little land use data are available by soils. In the U.S., however, we have much better data by political boundaries to work with.

CONCLUSION

In the U.S. we sample land for a Conservation Needs Inventory of soils, land use, and conservation practices by physiographic and political boundaries. We also sample (different area-frame sample) farms and land to produce annual land use and production data by political boundaries. We soil-map farms and have accumulated the information to do county soil surveys on about one-half of the counties in the U.S. Generalized soil maps are very scarce for large-area planning and the technology of

aggregating either CNI or detailed soil mapping to broad analytical units is not well developed. Data sets are independent and difficult to merge without a great loss of reliability.

In developing countries, we have an opportunity to improve greatly on the integration of data sets. Why two independent samples? Why not use a single sample for a soil inventory and production data? Why not use the same soil system for detailed farm planning and aggregate analysis?

We think we have conceptualized the beginning of such a process. RPUs are functional planning and implementation regions. Area-frame samples are functional data units. Area-frame samples are stratified according to land use and type of agriculture. We are exploring the integration of a CRIES-type land inventory into the design of an area-frame sample so that expansion properties would apply to physiographic units as well as political boundaries. This could create planning data directly appropriate to planning units. Moreover, if the sample plots were soil mapped as in the CNI, estimates of soil capability and extent could also be expanded to planning regions as well as political boundaries and directly related to use and production data.

It will take many disciplines to accomplish this total integration. We will make mistakes but eventually it can be done. Workshops such as this can make a great contribution toward integrating the concepts and methodology necessary for success.

LITERATURE CITED

SCIENCE AND EDUCATION ADMINISTRATION, UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). 1978. Crop climate taxonomy, a second approximation. Unpublished staff report. Science and Education Administration, USDA, Washington, D.C.

SOIL SURVEY STAFF. 1975. Soil taxonomy, a basic system for soil classification for making and interpreting soil surveys. Agriculture Handbook No. 436. Soil Conservation Service, U.S. Dept. Agric. U.S. Govt. Printing Office, Washington, D.C.

The Role of Soil Surveys in the Decision-Making Process for Development Planning

Ellis G. Knox

Soil surveys present factual information about one of our most important land resources and provide predictions about how that resource, the soils, will behave or perform under new and untried conditions.

Development planning attempts to devise programs and projects to improve the utilization of resources, including human, land, economic, and technical resources, to achieve increased production, greater efficiency, higher-quality products, better environmental conditions, or some combination of desirable goals. Much development planning is concerned with land use and management for agricultural, silvicultural, or other vegetation-based land use. Sound decisions for this planning require the information and predictions supplied by soil surveys. Other important land uses, dependent on soil characteristics but not related to plant growth, are not considered in this paper.

There are good reasons for restraint in making this claim about the role of soil surveys and for skepticism about the effectiveness of planning for economic and agricultural development. After all, the major part of the world's agricultural technology was developed and applied to particular land areas without benefit of soil survey and planning, largely by trial and error involving innumerable individual farmers. For example, much of Oregon's pear production is on Vertisols. How could any soil scientist have been wise enough to predict that pear trees could survive, let alone produce, on these difficult soils? Many farmers attempted to establish orchards throughout southern Oregon. Many failures resulted from these widespread trials on diverse soils, but the suitability of the Xererts for pear production was established in the process. Failures, at best, give inadequate or no production; at worst they degrade or destroy the land resource, eliminating the possibility for future trials. The role of soil surveys and development planning is to substitute for trial and error to the fullest extent possible and to eliminate predictable failures in production and in resource conservation.

FOUR MAJOR AREAS OF DEVELOPMENT PLANNING

Overall program development

At this level, the major orientations of development are established. Decisions are made about production for internal food needs vs. exports, agriculture vs. forestry,

grazing vs. cropping, dryland cropping vs. irrigation, hand-labor methods vs. mechanization, small farms vs. large plantations, and so on. Within the orientations established, ideas for specific development projects are formulated in broad outline. Obviously, the soil resources are only one factor among many, but in many cases the soils factor is critical for achieving the best decisions and projects.

Selection of areas

Programs must be applied to specific regions and projects are carried out in specific areas. Although considerations of existing infrastructure, population distribution, and distances to markets and sources of supply are very important, in many cases the soils are the dominant factor in selection of areas to achieve the greatest production, the lowest costs, the least environmental damage, the most efficient utilization of resources, etc.

Project development and feasibility

Once a project for a specific area is identified, the next step is to develop quantitative plans in sufficient detail to establish the physical and human inputs, estimate costs, and predict returns. This is the basis for determining the feasibility of the project and the relative desirability of alternative projects. Soils control yield, technology, and costs. Consequently, they are crucial for this step in the development process.

Operational planning and implementation

The actual execution of a project demands even more detailed planning and decisions. These include exact field lay-out; locations of fences, roads, and ditches; choice of machinery; type of irrigation; kind of sustained management; etc.

ROLE OF SOIL SURVEYS

For all four of the planning stages, soil surveys provide determinations and predictions of the following soil qualities:

Susceptibility to deterioration

For the great majority of soils, erosion is the most obvious and serious hazard resulting from agricultural or other vegetation-based land uses. Susceptibility to erosion must be recognized and emphasized in all soil survey activities.

We seldom consider the other ways in which soils can be damaged or destroyed when brought into use. Identification of soils susceptible to deterioration is an important contribution toward successful development planning.

Important hazards restricted to specific soils include hardening of plinthite with clearing and drainage of Plinthaquepts, Plinthaquox, and other soils; formation of acid sulfates with drainage of Sulfaquents and Sulfihemists; burning and subsidence of Histosols; salt and sodium accumulation in soils irrigated without adequate leaching, and hardening of portions of Hydrandepts exposed to drying. Development planners should be informed of the seriousness of these hazards and of the land uses and management practices that must be avoided to prevent deterioration.

With agricultural use, almost all soils are susceptible to exhaustion of the original supply of nutrients (in one or five or one hundred years, depending on the soil), to

downward adjustments in organic matter content under dry farming conditions, and to some loss of tilth. These losses are largely inevitable consequences of the cropping system.

In many cases, the levels of organic matter in equilibrium with the cropping system are adequate to maintain suitable physical conditions and nutrients can be supplied in fertilizers at reasonable cost. In these cases, the extra production or lower costs in the first years of production are what Marlin Cline has called "God's gift to pioneers." Long-term planning should be based on the behavior of the soil faced by the children and grandchildren of those pioneers.

On the other hand, deterioration resulting from exposure of the soil surface and clean tillage is quite serious for some soils, particularly those in very humid tropical areas. These soils should be identified and interpretations presented for cropping systems that maintain continuous vegetation or mulch cover and eliminate or reduce tillage.

Susceptibility to deterioration is a very important soil quality and one that needs to be considered early in development planning. Responsible and satisfactory land use and management must conserve the basic resource for future production. Fortunately, it is a relatively straight-forward prediction that in most cases can be made quickly and presented briefly and simply to the planners because it depends largely on soil characteristics that are already considered in the definition of soil units.

Suitability for management operations and land preparation

Most land management operations are carried out by means of hand labor, animal traction (or portage), or motorized machinery at some scale. In some cases, harvest is carried out by grazing animals. Development planners need to know how easily the management operations can be performed on specific soils.

Management operations of interest here include the full range of soil and plant management practices. In developed, temperate countries it is easy to think of the use of chemicals as somehow dependent on the use of machinery. Of course, this is not so; the most sophisticated fertilizer or pesticide applications can be made by hand. Moreover, wage scales, economic conditions, population pressures, and kinds of crops grown in many developing countries make hand labor and animal traction realistic alternatives to motorized machinery. For these reasons, planners need to have information about the suitability of the soils for management operations separate from predictions about productivity and hazards of deterioration. Criteria for the evaluation of the suitability include slope, depth, rock fragments, limitations on field size due to gullies, rock outcrops, etc., and wetness (Knox et al., 1975).

Irrigation and drainage are management operations that require somewhat different considerations. Specific methods need to be considered separately. For example, soils well suited for sprinkler irrigation may be poorly suited for furrow irrigation because of irregularity of slope or poorly suited for flood irrigation because of excessive permeability.

Still other considerations apply to evaluation of soil suitability for the operations required to prepare the land, such as clearing, leveling, diking, fencing, road construction, and so on.

Obviously, not all soils need to be rated for all kinds of management operations. Soil scientists should consult with crop scientists, planners, economists, and others to select the kind of technology pertinent to planning in specific regions.

Response to management

Predictions of productivity are meaningful only when yield is related to the set of management inputs required to achieve that yield. Development requires change in land management and in developing countries large differences in management inputs are common. Predictions may be required for several quite different combinations of inputs. Large interactions between specific inputs are very common, so it is necessary to consider the complete system of practices.

In economic terms, the net income is more important than the gross income. Accordingly, the difference between input (corresponding to costs of production) and yields (corresponding to gross income) is at least as important as the yield itself.

Systems of management practices should be based on considerations of susceptibility of the soils to deterioration and suitability for management operations. The amount of detail in specification of the system depends on the level of planning. For project feasibility, the inputs must be defined so that accurate cost estimates can be made.

The yield prediction can seldom be taken directly from yield observations. More commonly, the prediction must be extended geographically or from one kind of soil to another, or both. In many cases, adjustments must be made for differences in management between the few field observations available and the conditions of the predicted yield. Yield data are expensive, and require years of observations. It is almost safe to say that the information is never sufficient. Soil survey interpretations should indicate the reliability of the yield predictions and stress the need for small-scale field experimentation and pilot studies ahead of full commitment to large projects using innovative technology. In a feasibility study for a large upland rice project in Africa, the Soil and Land Use Technology team found they had to make a yield prediction based on one variety trial on-site without sufficient management information, one machinery experiment on-site without satisfactory yield measurements, experience with sugar-cane in an adjacent project area, extensive experimental and project yield data from other parts of the same country on quite different soils, and the general worldwide fund of information about management and yields of upland rice. Obviously, we recommended pilot studies before construction of the rice factory.

Constraints on land use

In addition to the interpretations included above, a separate consideration of the limitations of land use and management focuses the attention of research scientists and development planners on possible points of attack. Identification of constraints facilitates the development and selection of alternative management systems to overcome or compensate for specific soil constraints and the design of reclamation projects to eliminate the constraints.

Some constraints are permanent (e.g., slope); some can be eliminated permanently (thin, shallow duripan); some can be removed but require continuing attention from time to time (restricted drainage); and some can be overcome with continuing management (lack of nutrients). The soil surveyor needs to help make these distinctions. He also should identify the nature of the constraint. That is, he should indicate whether it limits plant growth, interferes with harvest, hinders the management operations, or leads to deterioration of the soil.

CONCLUSIONS

Soil surveyors often have bad news to tell. Soil resources commonly have less potential and stronger limitations than planners, economists, politicians, and the general public want to believe. World around, the best areas of agricultural development have already been found and exploited. Many areas now being farmed with traditional, labor-intensive methods are producing as much or more than would be possible with highly-mechanized modern methods. Many countries with low or moderate overall population density have such a high proportion of poor soils that they have a severe population problem. The soil surveyor must document his predictions very carefully and fully because there will be a strong tendency to discount any that are disappointing.

Because so much of our news is bad, we should be alert for soils with good development potential and for management systems that make the most of available resources. But, we must be forthright about limited soil resources and production potentials and about the need for development planning to consider both sides of the population-resource problem.

LITERATURE CITED

Knox, E. G., R. Low, J. Pichott, and H. Villota. 1975. Clasificacion de Suelos por su Potencialidad Productiva, V Congreso Latinoamericano de la Ciencia del Suelo. (Medellin, Colombia, August, 1975). (In press.)

The Value of Soil Resource Inventories in National Research Planning

M. C. Laker

Evaluations of soil resource inventories usually deal with their usefulness for the physical planning of land (e.g. regional planning, project planning, farm planning) or for the operational planning (management planning) of farming units (See Soil Resource Inventory Study Group, 1978). This paper deals with the value of soil resource inventories for research planning.

The emphasis will be on agricultural research, firstly because agricultural development forms the mainstay of rural development processes, and secondly because it is the field in which the author has some experience. The main focus will be on agricultural research in (and for) less developed areas.

PRINCIPLES RELATED TO AGRICULTURAL RESEARCH IN LESS DEVELOPED AREAS

The following are three of the most important principles required for effective agricultural research in less developed areas:

1. The research must be development and/or problem oriented. This means that all research must be directly aimed at bringing about development or solving existing identified problems — irrespective of whether it is "basic" or "applied" research. Less developed countries do not have the time and trained manpower (and the vast majority also not the finances) to indulge in the luxuries of "academic" research. This does not mean that their research should be of inferior quality. On the contrary, the quality of research must be very high. In addition, problem-oriented research is more challenging and often requires higher degrees of ingenuity than purely "academic" research.
2. The research must be conducted in such a way that the maximum reliability and geographic scope can be achieved in regard to technology transfer (i.e. in regard to practical application of research results).
3. To be truly efficient, the majority of development- or problem-oriented research requires at least some degree of interdisciplinary cooperation. A large proportion of the research actually requires a major degree of interdisciplinary liaison.

SOIL RESOURCE INVENTORIES IN RELATION TO RESEARCH UTILITY AND EFFICIENCY

Research workers from a variety of disciplines are involved in soil-oriented research. Only a few selected examples can be indicated here:

Soil scientists
Various types of soil scientists, e.g. soil chemists, soil physicists, soil microbiologists, etc., conduct research on such aspects as interactions between plant nutrients and soils (with a view to evaluating nutrient availability, efficiencies of fertilizers, etc.) and soil-water relationships (with a view to irrigation planning, rainfed cropping planning, etc.).

Crop scientists
Various types of crop scientists, including horticulturists, geneticists, etc., conduct research on such aspects as adaptability of different species and cultivars (varieties) of crops to different environments (including different soils); comparison of various crop production techniques; etc.

Rangeland and animal scientists
Carrying capacities and nutritive values of natural veld, nutrient element deficiencies, etc. are research topics which are soil-related (See, for example, Kubota, 1977).

Agricultural engineers
The suitability of different soils for the construction of earth dams and irrigation canals is but one of the numerous soil-related topics in this field (e.g. Scotney, McPhee and Russell, 1975).

Agricultural economists
Research regarding the economics of different farming systems; evaluation of the relative profitabilities of different classes and types of tractors and other implements, etc. are all soil-related.

Research results which are soil-related, i.e. which are affected by the nature of the soil at the point where the research was conducted, are of little (if any) value for planning or extension purposes if the nature of the soil (or soils) on which the results were obtained are not clearly indicated. Without adequate characterization of the conditions prevailing at the point where the research was conducted (i.e. soil, climate, etc.) it is impossible to make a reasonably reliable prediction of the validity of the results for any other area of land.

Unfortunately, a very large proportion of the research data collected from many parts of the world by agronomists, economists, soil chemists and soil physicists in the past is "characterized" by the lack or inadequacy of soils information. At the most, some analysis of the topsoil was sometimes given. This lack of appreciation for the need for adequate background soils information is undoubtedly a major factor responsible for the type of situation described by Protz (1977): "The soil management

literature was reviewed for specific soil properties affecting each crop. Precious little information was available beyond the standard—this crop grows best on deep, well-drained, friable, highly fertile soil—Obviously, if a decision was to be reached on which crop had the best chance of economic success on the poorer soils, more specific soils criteria were required."

A number of important practical implications arise, such as the following example: A group of planners must draw up recommendations regarding the development of an underdeveloped area. Masses of relevant information on which they could base reliable decisions are available from research elsewhere in the country or from other parts of the world. Because these relevant data are not supported by adequate background soils and other environmental information they can not identify it and use it advantageously. Instead of being able to make estimates, they must now base their decisions on "guesstimates." This may well lead to failure of the project and misery to the rural people involved.

On the other hand, it is of just as little use if the soils on which experiments are conducted are described in detail but there are no, or insufficient, soil resource inventories available for the rest of the county, region, or country. An extension officer may know that the research findings can only be extrapolated to land areas similar to that on which the research was conducted. If he does not have an indication of where in his extension ward such similar areas occur, then the research is of little or no benefit to him (and to the farmers whom he serves). The money spent on the research can be written off as a complete waste or loss.

Such unavailability of soil resource inventories may even lead to drastic misinterpretations and incorrect recommendations such as the following example: In the province of Natal in the Republic of South Africa a very severe potassium deficiency was identified in certain soils of the regional research station at Cedara. Good yields required high potassium applications. Based on these results, high levels of potassium fertilizers were recommended for large parts of the region. After many years it was realized that the potassium-deficient soils actually cover only an odd minority of the region. Many farmers were actually wasting large sums of money by buying the potassium fertilizers (Graven, Professor of Agronomy, University of Fort Hare, Alice, Republic of South Africa—personal communication).

This example leads to another aspect related to the interrelationships between soil resource inventories and research planning: In many cases new soil resource inventories reveal that existing experimental plots are actually located on soils that are sub-dominant, or even rare, in the region served by these experimental stations. Reliable extrapolation of research results from these plots is, therefore, very limited. Meanwhile no reliable information is available for the major part of the region. Alternatively, the soil of the experiment site may be a dominant soil in the area, but may not be generally used by farmers for the production of the crop on which the research is concentrated. If the objective of the research is to supply information to these farmers, then this research is a failure.

Categories of research of which the "delivery factor" depends upon soil resource inventories include, *inter alia,* the following:

Literature research

Scanning existing literature for applicable information upon which reliable planning or advisory (extension) decisions can be made, is a fast and inexpensive type of research.

Basic laboratory and greenhouse research

Ensuring that samples are collected at representative sites and that the soils at these sites are described adequately increases the utility of the research.

Field experimentation

The benefits from soil resource inventories are obvious and have already been discussed in this paper.

Observational research

Much useful information for planning and advisory purposes can be obtained from systematic and well-planned observations about crop-soil relationships under normal farming conditions. Extrapolations from such observations are meaningful only if the soil characteristics at each point of observation are well described and if a soil resource inventory is available for the area where the data are to be used for planning or advisory purposes.

Demonstration experiments

Although these are not actual research, they form a very important link in the process of "delivering" research information to farmers. The value of such an experiment is low when it is conducted on a rare soil. Even if it is conducted on a dominant soil every farmer needs to know whether the results of such a demonstration are applicable to any specific area of land on his farm.

Although crop-soil research was used as an example in the previous discussions, the same principles are valid for all other soil-related research.

RESEARCH PLANNING AIMED AT MAXIMIZING THE EFFICIENCY OF SOIL-RELATED RESEARCH

Taking into account that there are apparently at present only about six countries in the world that are net exporters of food and that populations are growing fast, it becomes clear that time is the most important factor demanding maximum efficiency from soil-related research. This need for maximum efficiency is amplified by the limited trained manpower and research funds available in many parts of the world.

A high efficiency means that extrapolation of the research data must have both (i) a relatively large potential geographical scope, and (ii) a high degree of reliability in regard to those land areas to which it can be extrapolated.

Planning future soil-related research so as to achieve maximum efficiency means that all possible care must be taken to (i) avoid the types of mistakes, and (ii) follow the types of guidelines outlined in the previous section of this paper. Reaching of these ideals is dependent upon three prerequisites: (i) availability of high quality soil resource inventories, (ii) an effective soil classification system, and (iii) correct attitudes by all scientists doing soil-related research towards soil resource inventories and soil classification.

Availability of soil resource inventories

The way in which soil resource inventories can (and should) guide research planning can best be illustrated by two examples:

1. Vink (1975) correctly advocates the establishment of "pilot projects" in all areas where the present land use is vastly different from what the potential future land uses are. He also stresses that, due to high costs and other limitations, these projects can only be conducted on a limited number of different "land units." It is obvious that such pilot projects can only be efficient if it is ensured that the research is done on the dominant soils in the study region with potential for the specific farming enterprise under investigation. Less reliable extrapolations then only have to be done to subdominant or rare soils. Without a soil resource inventory the dominant soils cannot be identified, nor can the pilot projects be sited correctly on representative locations.
2. During a recent exploratory soil survey of the Ciskei, an area on the southeast coast of South Africa, the author identified a large proportion of the arable soils as having a very low potential for maize, but a moderate (to high in some places) potential for small-grain cereals such as wheat (Hensley and Laker, 1978). At present South Africa as a whole is, furthermore, producing a large surplus of maize, with additional maize areas which can be developed. Wheat shortages are expected in the foreseeable future, however.

At present the traditional small farmers in the Ciskei are trying to produce maize on these lands (with disastrous effects). There are two factors mitigating against wheat production: (i) the traditional attitudes of the farmers, and (ii) severe incidences of rust infestation. The research needs have clearly been revealed by the soil resource inventory: (i) plant breeding research to develop wheat cultivars which are adapted to this specific area and are rust-resistant, and (ii) sociological and extension research to identify strategies to persuade the farmers to adopt wheat production instead of maize production.

An effective soil classification system

Soil resource inventories which are not based on well-designed soil classification systems have relatively low utility. A well-designed soil classification system must have the following characteristics:

1. It must be comprehensive, i.e. it should be capable of accommodating all of the soils to be found in a country. "Parochial classifications of a farm, a district, or a region can serve a very useful purpose for a time, but because of their restricted vision they do not serve the needs of soil users on a country-wide basis. A national perspective is required directly by many agriculturalists, ecologists and resource scientists and, indirectly, by all." (MacVicar et al., 1977).
2. Class definitions must be clear, rigorous, mutually exclusive, and based on factual statements of soil properties (Hensley, Senior Lecturer, Department of Soil Science, University of Fort Hare, Alice, Republic of South Africa—personal communication; MacVicar et al., 1977). This is especially important for the lower categories of classification, i.e. at series level and one level above series level.
3. Only soil characteristics that are easy to measure and to comprehend must be used for the definition of diagnostic horizons and soil classes. Criteria to be avoided include those that are difficult to measure or are not always measurable because they require sophisticated or continuous long-term measurements and those which "involve speculation (such as genetic history)" (MacVicar et al., 1977). An important aim is to have a system that is simple enough to enable

para-professionals or technicians in soil science, and even non-soil scientists, to make accurate soil identification in the field (MacVicar et al., 1977).

4. The classification system must be well-structured, so that the similarities and differences between soils can easily be understood. The aim is to find a simple way to permit more accurate communication about soils and to promote a better understanding of the relationships that exist among soils, and between soils and the environment (MacVicar et al., 1977).

In summary it can be said that the soil classification system must be practical. With this it is not meant that it must be a "technical" or purely "utilitarian" system. Such systems in the end really have low utility (Kellogg, 1961; Laker, 1978). A soil classification system must give "non-specialist users in many spheres the confidence and perspective to exploit soils information more fully." Only then can it promote "the development of a sound basis for predicting soil behavior and management responses under defined conditions." (Quotations from MacVicar et al., 1977).

If a country does not possess a soil classification system which satisfies these requirements, especially in the lower categories, then the development of such a classification system should be a very high research priority. (Note: A useful classification system need not be a local one, but may be a foreign one that is applicable to local conditions.)

Correct attitudes toward soil resource inventories and soil classification

Planning of soil-related research in such a way that maximum efficiency is acquired is impossible if the scientist conducting the research does not have a positive attitude toward soil resource inventories or soil classification. The correct positive attitudes can only be developed by means of a realistic perception of both the advantages and the limitations of high quality soil resource inventories and systematic soil classification systems. Unfortunately a large proportion of the scientists involved in soil-related research seem to have a strongly biased outlook on soil resource inventories.

On the one hand many non-soil scientists and soil specialists in other fields than pedology are so preoccupied with the limitations of soil resource inventories based on systematic soil classification that they overlook the potential advantages of such inventories. As a result of this bias they plan their research without taking soil resource information into account at all, with detrimental effects on the efficiency of their research.

On the other hand many potential users of soil resource inventories are antagonized by the highly presumptuous claims by some pedologists about all the "instant wonders" that could supposedly be achieved by the use of soil resource information. Soil resource inventories and soil classification systems are not magical things. They are only scientific tools, but very useful tools if used judiciously. Only when the indicated biases are eliminated, will a researcher give soil resource inventories their rightful place in the planning of soil-related research.

CONCLUSIONS AND STRATEGY PROPOSALS

The well-known, disconcerting gap between agricultural research and the extension of its results can be traced largely to the absence of a reliable basis for extrapolation (MacVicar et al., 1977). A well-designed soil classification system, high quality soil

resource inventories, and optimal exploitation of these during the planning of soil-related research are essential prerequisites for the establishment of a reliable basis for the extrapolation of research data.

A strategy consisting of three major steps (which could in terms of time overlap each other) is proposed:

1. Development of a well-designed, systematic and comprehensive soil classification system in the lower categories (series and one level above series) for each subcontinent. It must have all the attributes (simplicity, etc.) described earlier in this paper. The author and his colleagues have had the opportunity to use the new South African soil classification system (MacVicar et al., 1977) for advisory purposes in regard to project planning and even production planning and have seen the tremendous practical value of such a system in regard to data extrapolation.

Every country does not have to have its own system. The geographical scope of technology transfer and data extrapolation widens appreciably if all the countries having similar general soil patterns in a specific sub-continent are using the same system. Cultural and linguistic similarities between the countries involved will enhance the efficiency of technology transfer.

The FAO could make a tremendous contribution by identifying and demarcating these "pedo-subcontinents" and by guiding the development of lower category soil classification systems for each. (The author cannot foresee a humanly comprehensible and practically useful single soil classification system for the world as a whole in the lower categories. If all the systems are well-designed, then it will be fairly easy to "translate" from one system to another when necessary.) Much emphasis is placed on the lower categories, because these are the truly practically useful categories.

2. Compilation of soil resource inventories, using such a well-designed classification system. To be successful, the definitions, etc. embodied in the system must be rigorously applied by everybody using the system. (Carelessness and negligence lead to much confusion and loss of confidence in soil resource inventories by non-pedologists.) Very rigorous correlation is also required to ensure that everybody using the system is using it correctly. This may be a problem where more than one country is using the same system.

3. "Selling" the classification system to non-pedologists by discussing it with them during its development and taking note of any good suggestions from their side; explaining the final product to them and planning soil resource inventories together with them. The main objective is to entice them to exploit soil resource information optimally when planning their research.

In South Africa such a series of exercises have been proceeding during the last two decades. The need for a systematic soil classification system for the country was recognized and one was drawn up (MacVicar et al., 1977), using the general principles outlined in the "7th Approximation" (Soil Survey Staff, 1960) as a blueprint to copy. Overlapping with the development of this system, "pedosystem" mapping of the country as a whole is now being conducted on a scale of 1:250,000 (MacVicar et al., 1974). It is almost completed. Picking up momentum now is a project of "norm" collection (i.e. collection of quantitative data regarding crop performance for different crops, etc.) which is done countrywide on an "ecotope" basis. According to MacVicar et al. (1974) an ecotope is an area of land that is defined so narrowly in terms of soil, macroclimate, and slope that in terms of the potential yield class for each feasible farming enterprise or the production techniques needed for each such enterprise, there

is a significant difference between one ecotope and any other. Various non-soil scientists are participating on this project. Furthermore, soil scientists have explained the aims, characteristics, etc. of the classification system and the pedosystem survey by means of short courses, meetings, and personal deliberations to non-soil scientists. The result is that a large percentage of them have accepted it and are using it to great advantage in the planning of their research and the extrapolation of research data.

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LITERATURE CITED

Hensley, M., and M. C. Laker. 1978. Land resources of the Ciskei. p. 3–17. *In* M. C. Laker (ed.) The agricultural potential of the Ciskei—amended report. University of Fort Hare, Alice, Republic of South Africa.

Kellogg, C. E. 1961. Soil interpretation in the soil survey. U. S. Government Printing Office, Washington, D.C.

Kubota, J. 1977. Role of the soil survey in trace element studies. p. 163–176. *In* Soil resource inventories: Proceedings of a workshop held at Cornell University, April 4–7, 1977. Department of Agronomy, N.Y. State College of Agriculture and Life Sciences, Cornell University, Ithaca, NY.

Laker, M. C. 1978. Soil science in relation to development processes in less developed areas. Paper presented at the 8th National Congress of the Soil Science Society of Southern Africa, Pietermaritzburg, July 11–14, 1978. (Proceedings in press).

MacVicar, C. N., D. M. Scotney, T. E. Skinner, N. S. Niehaus, and J. H. Loubser. 1974. A classification of land (climate, terrain form, soil) primarily for rainfed agriculture. S. Afr. J. Agric. Extension 3:21–24.

MacVicar, C. N., J. M. De Villiers, R. F. Loxton, E. Verster, J. J. N. Lambrechts, F. R. Merryweather, J. Le Roux, T. H. Van Rooyen, and H. J. von M. Harmse. 1977. Soil classification: A binomial system for South Africa. Department of Agricultural Technical Services, Pretoria, Republic of South Africa.

Protz, R. 1977. Soil properties important for various tropical crops: Pahang Tenggara master planning study. p. 177–188. *In* Soil resource inventories: Proceedings of a workshop held at Cornell University April 4–7, 1977. Department of Agronomy, N.Y. State College of Agriculture and Life Sciences, Cornell University, Ithaca, NY.

Scotney, D. M., P. J. McPhee, and W. B. Russell. 1975. p. 276–289. *In* Soil survey interpretations for earth dams. Proc. 6th National Congress of the Soil Science Society of Southern Africa. The Soil Science Society of Southern Africa, P.O. Box 1821, Pretoria, 0001, Republic of South Africa.

Soil Resource Inventory Study Group. 1978. Guidelines for soil resource inventory characterization (draft paper). Department of Agronomy, Cornell University, Ithaca, NY.

Soil Survey Staff. 1960. Soil classification: A comprehensive system—7th Approximation. Soil Conservation Service, USDA, Washington, D.C.

Vink, A.P.A. 1975. Land use in advancing agriculture. Springer-Verlag, New York, N.Y.

PART ONE

SOIL RESOURCE INVENTORIES

Section IV

Soil Properties Important for Given Land Uses

The Selection of Soil Properties and Land Qualities Relevant to Specific Land Uses in Developing Countries

Klaas Jan Beek

Soil information can play an important role in solving land use problems that farmers face in developing countries. To make a significant contribution, data collection, which is necessarily a selective process, has to be problem-oriented. The soil properties that should receive attention will depend on the existing land use problems, the detail of the study, and the criteria for optimal land use. The most common criteria for optimal land use are favourable input-output relationships and conservation of the environment (the latter in terms of sustained production capacity and environmental quality).

In developing countries we usually meet with a technological transformation continuum: modern and traditional land use operate side by side, sometimes linked by land uses characterized by so-called intermediate technologies. If we focus our attention on the more traditional types of land use and the possibilities for their development, we should recognize another, probably overruling criterion for optimal land use: minimal risk.

MINIMAL RISK IN DEVELOPING AGRICULTURE

Traditional agriculture aims at minimizing risks to assure a continuous food supply, often of a low nutritional standard, for the family. Traditional land use represents a (precarious) balance between the productive capacity of the land and the production means of the rural family. It is a closed system, virtually without capital inputs, occasionally shaken by episodic hazards.

Population pressure may upset the balance of these systems. The result is often a degradation of the quality of the land, and social disaster. Soil survey in developing countries is expected to contribute to solving such problems. Sometimes, new areas of suitable land can be identified for settlement, but mostly there will be a need for the introduction of land use changes leading to intensification, based on capital inputs (especially for plant nutrients and water). Properties studied by soil survey should therefore be relevant, not only for an assessment of the soils under present manage-

ment, but also for predicting their response to specific inputs such as fertilizer, irrigation water, new farm equipment, etc. The introduction of such inputs in traditional agriculture has often resulted in disappointment; the traditional dependence of the small farmer on the natural environment is replaced by dependence on the commercial environment, accompanied by new, and sometimes fatal, factors of risk and uncertainty.

Obviously, soil survey has a responsibility to provide the information necessary to minimize the risks of a developing agriculture in its early, most vulnerable stages; the introduction of fertilizers needs an assured minimum effect, and the certainty that the cost can be repaid. The introduction of a more advanced plow should be made in a period when the moisture conditions of the topsoil (its "workability") permit its use. New seeds should be sown when the aeration, moisture, and temperature conditions are ideal for germination.

In developed countries, soil management and engineering can rely on high level research facilities and experience. In the Netherlands, for instance, an analog simulation model of the non-steady unsaturated flow of moisture has been developed to predict the moisture tension of the topsoil during springtime (Wind, 1979), an essential piece of data for the timing of field operations. The model also permits simulation of different tile-drain spacings and depths for optimizing the drainage conditions. Such a model can be most valuable for land use planning, reducing the risk and uncertainty related to the timing of plowing, seedbed preparation, sowing, etc. It could be applied to land use problems in developing countries if the necessary data were made available: rainfall data for a long enough period, evaporation, runoff, infiltration rate, and moisture characteristics of the soil.

The model is based on the following relationship between soil moisture tension and capillary conductivity: $k = k_0 e^{a\Psi}$.

k = capillary conductivity (cm day^{-1})
k_0 = capillary conductivity at zero tension
Ψ = soil moisture tension (cm), negative in unsaturated soil (workability limit = −300 cm in top 5 cm)
a = soil parameter
$k = 2.78e^{0.035\Psi}$ ($\Psi \geq -300$ cm)
$k = 0.0225\Psi^{-1.4}$ ($\Psi < -300$ cm)

The nutrient status of the soils of many traditional farmers has probably decreased to the point where additional inputs are essential. But, for continuous croppers, the risk of reducing the acreage under food crops may be too high to compensate for the mathematically proven advantages of including legumes in their crop rotation. Of course, shifting cultivators will be able to introduce green manures (in addition to the naturally occurring species) in their fallow land, without much additional risk.

PROBLEM-ORIENTED SOIL SURVEY

Data collection in soil survey is guided by standards that traditionally aim in the first place to solve soil classification problems. This paper is more concerned with the solution of land use problems, which requires a more complex body of information of which soil data is an essential part.

Even in reconnaissance soil survey, the main land use problems and development options are recognizable. Instead of standardized data collection for a high category of soil classification, it should be possible to collect some additional data such as infiltration capacity of sloping land occupied by traditional farmers, hydraulic conductivity of poorly drained bottom lands, pF values, data about aggregate stability, etc. Indeed, reconnaissance soil survey in Brazil includes collecting compound samples for soil fertility analysis. However, few soil survey manuals deal with specific purposes: the draft edition of FAO on soil survey investigations for irrigation is an exception (FAO, 1974).

FAO (1976) recently published a *Framework for Land Evaluation,* which explains the concepts and procedures of land evaluation for specific purposes. The procedures include a preparatory phase of interdisciplinary consultation or problem analysis where the more relevant land use possibilities or land utilization types are identified in terms of produce, technological level, management, scale of operations, capital, and labour intensity. The detail of such definitions will correspond with the intensity of land evaluation. The preparatory phase should also provide us with the already mentioned criteria for land evaluation and optimal land use planning (FAO, 1975).

Supposing that we are able to identify the relevant land utilization types for our target group—the poor farmer—then the next step should be to collect the pertinent information. The objectives of land evaluation as defined by FAO obviously refer to a broader information base than soils alone, but this should not discourage us.

Soil data and fundamental land use processes

When collecting soil data to solve land use problems of farmers in developing countries we must be fully aware of the farmer's soil-dependent activities. We should be able to concentrate on the fundamental processes and activities of the specific land use system (or land utilization type) and the role of measurable soil properties in these processes.

The question arises whether it will be possible, or realistic, to study soil properties in the light of fundamental land use processes. This depends on our interpretation of the term *fundamental*. For a biologist (de Wit et al., 1974), photosynthesis, respiration, and transpiration are fundamental processes. He may try to simulate, for instance, plant root growth as a function of variables such as soil temperature and soil oxygen, measured hourly or daily. Such precision may be possible in a program of meteorological data collection but not in soil survey. On the other hand, parametric methods which translate a set of measurable soil properties directly into expressions of productivity or suitability, based on correlations found statistically, pay little attention to the fundamental processes that take place. It seems that we should strike a balance between these two extremes.

To achieve this, land use (which is a continuous process) will first need to be subdivided into a number of specific activities for finite time periods, each with its own land demands and therefore possibly limited by one or more soil properties. A kind of check list of activities could be:

land preparation
sowing
fertilization
irrigation
drainage
germination

phytosanitary practices
vegetative development (roots, stems, leaves)
early vegetation growth (roots, stems, leaves)
rapid vegetation growth (roots, stems, leaves)
generative development (sexual: flowering, fruit and seed development, ripening and dissemination of seed; asexual: buds, layering, bulbs, tubers)
harvesting
fallow (rotations)
survival (perennials)
engineering (installation of irrigation and drainage systems, etc.)
maintenance (e.g. ditch cleaning)

Relating these activities to the various environmental regimes (energy, water, gas, biotics, nutrients, hazards, foothold, toxic elements) of the diverse strata of the environment (off ground, near ground, ground surface, soil, deeper sub-strata, or geophysics) should give us a first impression of which environmental regimes need careful examination. A problem, of course, is how to measure the time-variable regimes, and as far as this paper is concerned, the soil regimes. We may have to go to great lengths, by constructing an analog model mentioned earlier, to characterize a non-steady-state regime. Research, in its effort to construct sophisticated analog and computer simulation models, sometimes forgets that some concrete analog models may still be found in nature; the natural vegetation and present land use can reveal much of how hypothetical land use alternatives may be expected to perform. A good example from Brazil is the interpretation of the natural forest vegetation in terms of water availability (Bennema, Beek, and Camargo, 1964). Another example is the use of the natural vegetation as an indicator of soil permeability and soil salinity (Risseeuw, 1972).

The soil surveyor is in the exceptional position of being able to observe and correlate such phenomena to refine the prediction of soil behaviour under specific uses. He will need this ability, because soil surveyors will be increasingly asked to study soils with complex utilization problems; agriculture is now extending into areas of problem soils (e.g. heavy clays, acid sands, acid sulphate soil) that defied cultivation until recently.

Another problem arises when soil of low or medium potential is used in the absence of an alternative. Often the land of poor farmers in the humid tropics is located on steep but fertile slopes which, according to U.S.D.A. standards of land capability, should be reserved for forestry. In such marginal situations imaginative data analysis is needed, because classification in terms of "impossible" or "unsuitable" cannot change the situation. However, last year on two occasions our Institute had no other alternative but to advise against project development: the settlement of poor farmers on acid sands in the Western Province of Zambia, and on aluminum-saturated Ultisols in Indonesia. Decision-makers may not accept the conclusions of soil scientists, as happened with the land settlement on extremely poor kaolinitic Oxisols along the Trans-Amazon Highway in Brazil. However, the cost of a careful determination of soil properties is justified, even if the final conclusion should be negative.

Land qualities

It is difficult to characterize the soil regimes affecting agricultural processes: water, nutrients, gas, biotics, foothold, toxicities, and mechanical strength. It is also difficult to measure the soil conditions that affect successful management operations and

response to physical input. However, for the interpretation of soil information, attempts should be made to synthesize the relevant measurable soil properties into assessment factors that have a specific influence on these processes and activities. Therefore the concept of land quality has been developed.

A *land quality* can be defined as a component regime of the physical land conditions with a specific influence on land use performance. "Each land quality acts in a manner distinct from the actions of other land qualities in influencing the suitability of land for a specified kind of land use" (FAO, 1976). Kellogg introduced the term *soil quality* in 1961 for a similar concept, perhaps more in line with the subject of this workshop.

The following examples (from Beek and Bennema, 1972) illustrate different types of land qualities:

1. Major land qualities related to plant growth: availability of water, nutrients, oxygen for root growth, and foothold for roots; conditions for germination (seed bed, etc.); salification and /or alkalinization; soil toxicity or extreme acidity; pests and diseases related to the land; flooding hazard; temperature regime (including incidence of frosts); radiation energy and photoperiod; wind, storm, hail, snow, and air humidity as affecting plant growth; and drying periods for ripening of crops and at harvest time.

2. Major land qualities specifically related to animal growth: hardships due to climate; endemic pests and diseases; nutritive value or toxicity of grazing land; resistance to degradation of vegetation and soil erosion under grazing conditions; availability of drinking water; and accessibility of the terrain.

3. Major land qualities related to natural products extraction: presence of valuable wood species, fruits, game for meat and/or hides, medicinal plants and/or other vegetative extraction products; and accessibility of the terrain.

4. Major land qualities related to practices in plant production, animal production, or extractions: possibilities of mechanization, resistance to erosion; freedom in the layout of a farm plan or a development scheme, including the freedom to select the shape and size of fields; trafficability from farm to land; and vegetation cover in terms of favorable or unfavorable effects for cropping.

There is still much to be achieved in the quantitative measurement of land qualities. They are usually ranked on an ordinal scale, using threshold values to distinguish different levels. In Brazil, land qualities have been used since the reconnaissance soil survey of São Paulo (Lemos et al., 1960). Even night frost, a hazard to coffee-growing, was considered. Since then a data bank with a highly efficient reporting system has been set up in São Paulo. Although its use for predicting episodic hazards is still limited, the computer can print out maps of the effect of night frost on coffee plantations the day after the frost has occurred.

The concept of land quality is currently in use in FAO projects (Philippines, Indonesia, Sudan, Thailand) and in Netherlands bilateral technical assistance programs (Kenya, Portugal, Colombia). In the Netherlands too, the concept has been recognized and is now being developed for soil survey interpretation (Table 1). Although most of the soil properties that contribute to land quality are measured on a ratio scale, the land qualities themselves are mostly rated on an ordinal scale: high—medium—low—very low. Appendix I includes seven references to literature about land evaluation, which in one way or another incorporate the concept of land quality in their methodology.

The land quality concept represents a component regime or subsystem of the environment and has a known influence on the basic processes that control land use

Table 1. Land qualities or "site conditions" in the Netherlands soil survey interpretation methodology.

	Regarded as relevant for				Levels or gradations		Desired level determined	Refers to		Nature of conditions	
Site conditions	arable farming and hortic.	pasture production	forestry	recreation	recognized	quantitatively expressed		basic processes	management system	chemical	physical
Drainage status	X	X	X	X	X		X	X			X
Moisture supply	X	X	X	X	X		X	X			X
Workability	X				X		X		X		X
Structural stability	X				X		X		X		X
HC1—reaction/lime content	X				X	X	X	X		X	X
Bearing capacity		X			X	X	X		X		X
Spring earliness	X	X			X		X		X		X
Nutrient status			X		X		X	X		X	

Source: Gibbons and Haans, 1976, Table 3.

performance. When measuring and rating land qualities it will be useful to distinguish those threshold values of component properties that are pertinent for the use in question, e.g. in soil salinity, soil fertility, erosion hazard. For example, the limit of 300 cm H_2O moisture suction in the top 5 cm of the soil during one week is an example of a threshold value for the land quality workability in springtime in the Netherlands (Wind, 1976). The threshold value will depend on the type of land utilization. When recommending sugar beet production, the moisture suction value of the top 5 cm of the seedbed must be known; but for potatoes, the moisture condition of the top 7 cm of soil is required. For grain production, the information is required for only a few centimeters depth, as these seeds require a shallow seedbed.

Land qualities can be described and rated independently to express the status of component regimes of the environment during a particular time period. But the significance of these ratings and of the threshold values of component properties will depend on the knowledge of the specific land requirements of the use in question.

The kind of land use and the objectives of land use determine which land qualities are limiting and to what degree. The constraining effect of such land qualities will need to be assessed first for the already mentioned time-discrete land use processes and activities, and after that, by means of some kind of integration or critical path analysis, for the whole sequence of time-overlapping land use processes.

LAND QUALITIES, LAND IMPROVEMENT, AND LAND EVALUATION

Land qualities can provide a link between land resources inventories and land use planning by identifying the properties that merit observation, measurement, and classification and by suggesting the detail, in terms of number and density of observations, that is required. We measure only the essential qualities of the land so they can be used as independent determinants of the land quality-dependent effects or "outputs" resulting from a specific use of the land in question. Similarly to land qualities, these outputs are also often measured on an ordinal scale: e.g. very high, high, medium, low, or very low yields; high, medium, low, or very low soil erosion losses.

The relationship between certain levels of land qualities and the corresponding outputs to be expected if used for a certain utilization type can be presented in conversion tables (Table 2). These tables must relate each kind of output to land qualities that determine the output. Principal component analysis is useful for analyzing the influence of land qualities on the output (Bastide and Goor, 1970).

Land quality/output relationships

Often, a graphical presentation or "production function" is preferred to present the LQ/Y relationship. For this purpose, the multi-dimensional land quality vector is subdivided into a number of significant trajects according to values representing critical or "threshold" levels for the use in question, e.g. critical levels of soil salinity, nutrient status, or moisture conditions in the topsoil. Sometimes there will be only one critical level; sometimes there will be several, each corresponding with a different level of output. The choice of the number of levels of land qualities is free.

Table 2. Conversion table to convert land qualities to land suitability.

I					LUT_1	
II				LUT_1		LUT_2
III			LUT_1			
IV	LUT_1 LUT_2	LUT_1 LUT_2	LUT_2	LUT_2		

0 1 2 3 4 5 6

Y = outputs:
e.g.
Y_y = yield
Y_e = soil erosion losses
Y_s = soil salinization

LQ = Land Quality, e.g.
LQ_e = resistance to soil erosion
LQ_w = water availability

LUT_1 = Land Utilization Type 1
LUT_2 = Land Utilization Type 2
I-II-III-IV = output classes
0-1-2-3-4-5-6 = threshold values of land qualities used for distinguishing output classes

The land demands of the land utilization type determine the curvature of the function expressing the LQ/Y relationship. Thus, the same amount of available water (LQ_w) during a finite time period Δt can be more limiting for the yield Y_y1 of one crop (land utilization type 1) with water requirements a_w1 during that particular period, than for the yield Y_y2 of another crop (land utilization type 2) with water requirements a_w2 during that same period. Similarly, the same erosion susceptibility LQ_e during a finite time period Δt can lead to higher soil erosion losses Y_e1 when used for one crop (land utilization type 1) with erosion resistance demands a_e1 than for another crop Y_e2 (land utilization type 2) with erosion resistance demands a_e2. The values taken by a_w and a_e are parameters of the output/land quality relationships: $Y_{(LUT,LU)} = F(LQ_{(LU)}, a_{(LUT)})$

Land evaluation

One of the most critical aspects of land evaluation is the availability of information about the specific land demands, i.e. the values of the parameters of the types of land utilization under consideration. Most literature about the land requirements of tropical crops is vague about this.

The LQ values assumed for predicting the outputs Y_y, Y_e, etc. correspond with the levels of land quality resulting from management, improvement and conservation practices applied within the range of possibilities defined for the land utilization type in question.

However, land evaluation is often required to include an explicit assessment of the effects of specific physical input for management, improvement and conservation of the land qualities on land use performance; in other words, to analyze input-output relationships: $Y = F(LQ,I)$ in which

$$I = \text{physical inputs for the manipulation of LQ}$$

The ultimate goal of analyzing such input-output relationships, first in physical terms and subsequently in economic terms, is to select the optimal levels of output with a specification of the corresponding inputs. The meaning of "optimal" depends on the objectives and derived criteria of land use planning and development.

The land quality concept could be useful as an intermediate variable for analyzing the relationships between physical inputs for the management, improvement, and conservation of land resources and the effects or "outputs" to be expected from such inputs.

Systems analysis approach. Instead of an empirical site-specific analysis which ignores the underlying processes that control such input-output relations, I have proposed a more fundamental method of analysis, in a report to be published by ILRI in the latter part of 1977. In this study I attempted to introduce systems analysis in a staged multidisciplinary land evaluation procedure (Figure 1).

During the first stage *(problem analysis)* of the procedure the most relevant land use options or land utilization types are selected and provisionally defined. These land utilization types (LUT) have a strong influence on the kind and detail of data to be collected during the second stage (the *descriptive systems analysis*). Basically, two closely related systems are described: the land system and the land use system. In the light of the information produced during the description of the land system, the definitions of the land use systems or land utilization types are refined. Special attention is paid to the exact land demands of the land use during finite time periods in relation to each land use process or activity. The third stage is the stage we are most concerned with in this paper: *operational systems analysis*. Now a specific land use system is superimposed upon a particular land system, and its sequence of activities is simulated in order to predict the combined effects to be expected if this land use system were to act on this particular kind of land.

Since the land qualities of the land system comprise all component regimes of the physical environment, including such dynamic components as radiant energy and rainfall, the only additional physical inputs to the system are those applied for management, improvement, and conservation of the land system. These physical inputs represent the operational variables of the data analysis. Their value must be selected in such a way that the outputs take values that are closest to the objectives of the decision-makers (the planners, the bankers, the engineers, the farmers). The essence

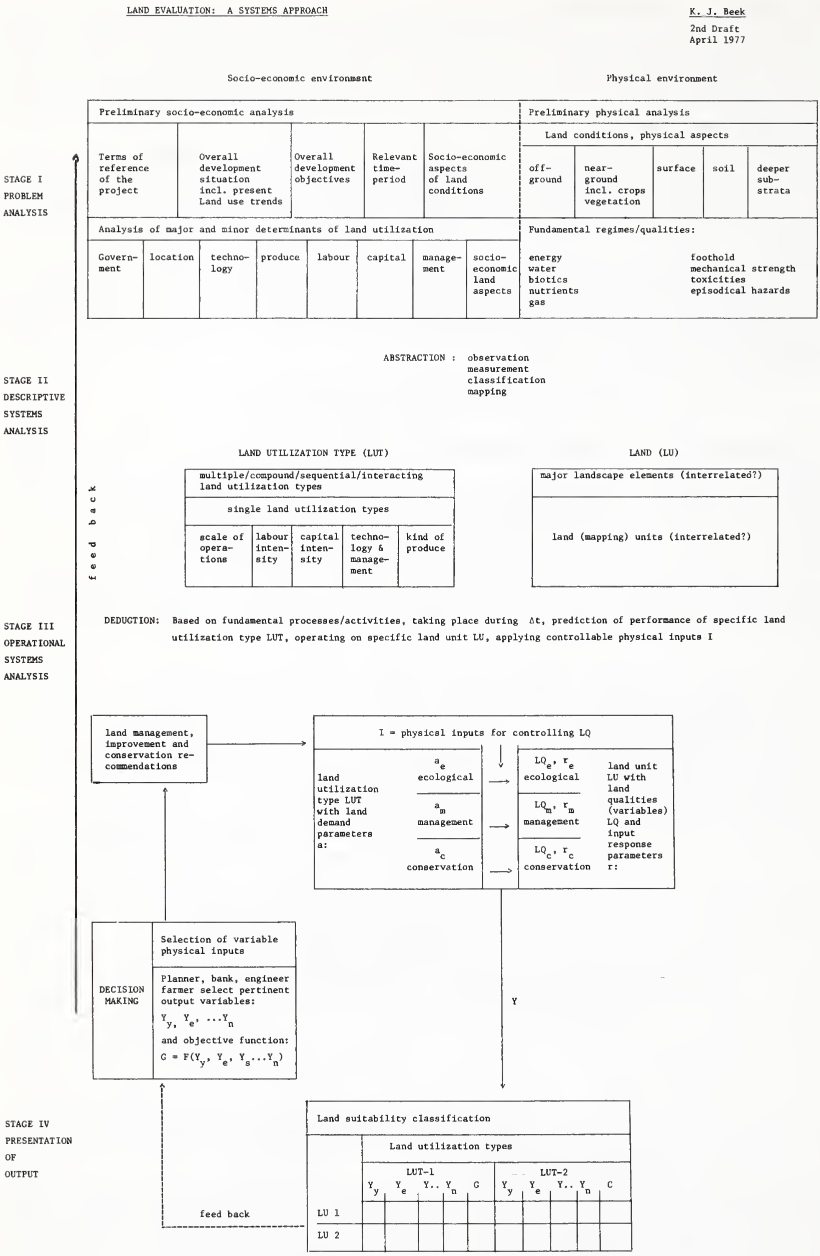


Figure 1. Land evaluation: a systems approach.

of stage three, operational data analysis, is the analysis of input-output relations and their optimization, based on fundamental processes taking place during finite time periods. Basically the data-analysis consists of two steps:

1. land quality/output analysis
2. input/land quality analysis

By combining (1) and (2) it becomes possible to carry out:

3. input/output analysis.

Land quality/output analysis

$$Y_{(LUT,\ LU)} = F\ \{LQ_{\ (LU)},\ a_{\ (LUT)}\}$$

In a purely physical land suitability classification it would be difficult to bring the multi-dimensional output $\{Y_y, Y_e, Y_s \ldots Y_n\}$ under a common denominator. Therefore, land suitability class distinctions will include criteria for each kind of output: expected yield, acceptable levels of erosion, salification, yield probability, etc. Commensuration of the multi-dimensional output into common (mostly monetary) terms is difficult and requires economic analysis, often based on mathematical optimization techniques and an objective function: $C=F\{Y_y, Y_e, Y_s, \ldots Y_n\}$. The physical inputs (I) will usually be selected in such a way that the objective function (C) takes the most favourable value. But in physical analysis, especially at reconnaissance and semi-detailed levels of land evaluation, simpler methods of analysis would be preferred. A practical way of presentation is by using step-functions; this seems in line with the proposed methodology using land qualities and threshold values for their component properties (Figure 2).

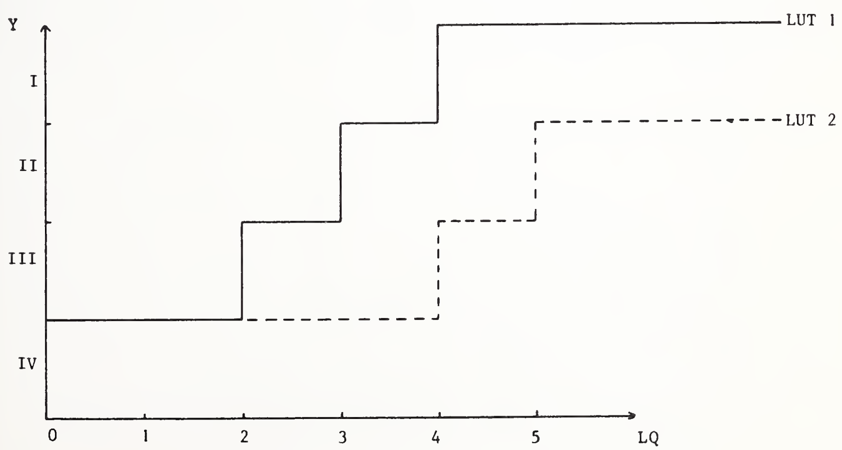


Figure 2. Step functions expressing output-land quality relation of two different land utilization types LUT_1 and LUT_2.

To this end the output vector is subdivided into a number of trajects, to indicate the expected levels or "classes" of output of the land use, depending on the threshold values of the land qualities. Sometimes the planners have specified beforehand the levels of output (the significant production levels for class distinction, the acceptable levels of salinity of drainage water and soils, the acceptable levels of risk of failure or crop damage).

The integral effect of all combined outputs is summarized in a land suitability class. For practical reasons, the number of suitability classes does not usually exceed three or four.

Input/land quality analysis

It will be necessary to distinguish between the levels of the unimproved land qualities: LQ_u, and the levels of the improved land qualities: LQ_i.

$$LQ_{i\,(LU)} = F\{LQ_{u(LU)}, I, r_{(LU)}\} \qquad \text{(see Figure 3)}$$

I = variable physical inputs required for improving the land quality $LQ_u \rightarrow LQ_i$ of land unit LU, if used for a specified land utilization type LUT.

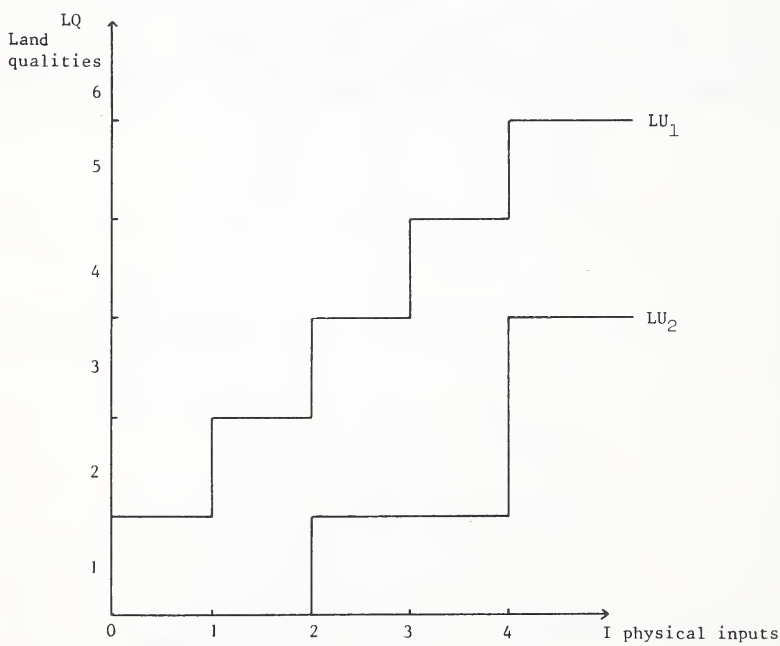


Figure 3. Step function expressing input-land quality relationship of two different land units: LU_1 with input response parameters r_1 and LU_2 with input response parameters r_2.

The physical inputs for management and conservation of LQ may also be included here, if a distinction between such inputs for different land units is considered to be relevant for the land suitability classification, e.g. a distinction in fertilizer applications or in physical inputs for soil conservation. This may be pertinent for detailed land evaluation. But in many cases the input/land quality analysis will be restricted to the study of the effects of major land improvements (such as irrigation, drainage, deep plowing) on the levels of the land qualities. $r_{(LU)}$= input response parameters of the land unit in question. One land unit will show a different response to input applications from another; it has different irrigation water efficiency or a different response to fertilizers because of different soil properties (texture, organic matter content, cation exchange capacity).

Such response parameters of the land units have also been named "response land qualities" (Bennema, 1976). Although handled as parameters in this context, because the influencing soil properties may often be difficult to modify, the input-response parameters may be modified if their influence on land use is paramount (e.g. by applying organic waste or soil conditioners).

Input/output analysis

By combining the relationships found in (1) and (2) we arrive at the relationships:

$$Y_{(LUT,\ LU)}=F\{I_{(LUT,\ LU)},\ LQ_{u(LU)},\ a_{(LUT)},\ r_{(LU)}\}\ \text{(Figure 4)}$$

CONCLUSION

Land evaluation should be able to analyze the relationships between the variable land qualities LQ, physical inputs I, and outputs Y on the basis of the underlying fundamental land use processes taking place during finite time periods. If this analysis can use exact information on the values of the input-response parameters of the land $r_{(LU)}$, and the land-demand parameters of the land use $a_{(LUT)}$, land evaluation should be able to make reliable predictions of outputs and corresponding physical inputs for specific

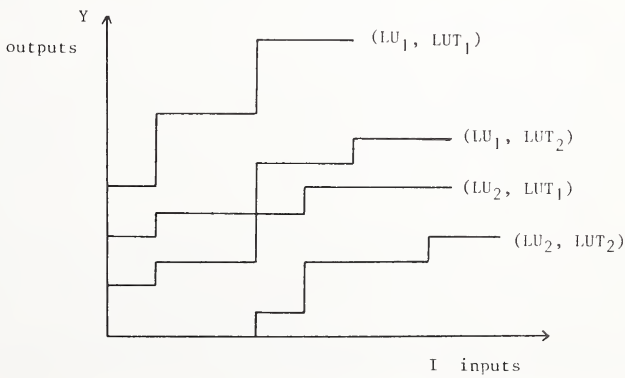


Figure 4. Step function expressing input-output relationship of two different land utilization types LUT_1 and LUT_2, acting on two different land units LU_1 and LU_2.

types of land use acting upon specified kinds of land. Being based on fundamental land use processes and formal scientific laws, transfer of analogy in agricultural research will be enhanced; this is very important for developing countries.

Soil survey in developing countries needs to be oriented towards analyzing specific land use problems. The fundamental land use processes influenced by soil properties are important. These processes are controlled by simple chemical and physical variables such as N_2, CO_2, O_2, NO_3, and NH_4, which are unfortunately very difficult to predict in terms of measureable soil properties for finite time periods. To help overcome this problem the land quality concept has been introduced. It is "a complex attribute of land, which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use" (FAO, 1976).

The land quality concept is in its early stages of development. If it can be developed successfully, the concept could serve several purposes:

- indication of soil properties deserving priority for study in soil survey;
- systematization of the soil surveyor's capacity to observe and interpret natural phenomena. Levels of some land qualities can be deduced directly from the present land use. Crops and natural vegetation stand model for the optimal land use systems as far as ecological processes and related ecological land qualities are concerned (Bennema, 1976);
- knowledge transfer to areas in developing countries with a poor data base for optimizing land use, because site-specific soil properties are synthesized into land qualities controlling fundamental land use processes; and
- improvement of the predictive value of land suitability classifications and the possibility of their periodical up-dating.

Vink (1975), in a book that gives a thorough treatment of land use in advancing countries and contains many references to soil survey and land evaluation, concludes that "the study of land qualities is an essential factor in the development of more complicated systems of land evaluation." However, a more fundamental approach to land evaluation should not necessarily be more complicated. Simplication will be possible if we succeed in mobilizing the soil surveyor's capacity for observing natural phenomena, by trying to measure (at least on an ordinal scale) some of the land qualities directly in the field. The soil drainage classes of the U. S. soil survey manual are an example. Also, in the Netherlands, soil surveyors have a special skill in the measurement of the soil permeability directly in the field on an ordinal scale, although there is a confirmed risk of discrepancies between ordinal measurements made by different individuals. Such measurements require correlation, calibration, and refinement with additional ratio scale measurements in the field and in the laboratory. Refinement of the techniques of interpretation of soil resources inventory data in general will give rise to critical questions about the accuracy of the data base [for example, concerning the variance in the measured soil properties and the degree of heterogeneity of soil/land (mapping) units]. These (mapping) units for planning purposes will be handled as homogeneous land areas with a homogeneous performance. Soil resources inventory reports need to be very explicit on this subject of variance versus accuracy.

Finally, I would appreciate hearing the opinion of the participants of this workshop regarding the prospects of developing the land quality concept further than has been achieved so far with the "limitations" of the land capability system, to provide a useful link between soil resources inventory and land use planning.

LITERATURE CITED

Bastide, J. G. la, and C. P. van Goor. 1970. Growth-site relationships in plantations of *Pinus eliottii* and *Araucaria angustifolia* in Brazil. Plant Soil 32(2):349–366.

Beek, K. J. 1978. Land evaluation for agricultural development, some explorations of land-use systems analysis with particular reference to Latin America. ILRI Publication No. 23. P.O. Box 45, Wageningen, The Netherlands.

Beek, K. J., and J. Bennema. 1972. Land evaluation for agricultural land use planning, an ecological methodology. Agric. State Univ. of Wageningen, Netherlands.

Bennena, J. 1976. Land evaluation for agricultural land use planning. Benchmark Soils Project, Univ. of Hawaii. (In press.)

Bennema, J., K. J. Beek, and M. Camargo. 1964. Soil survey interpretation for reconnaissance surveys in Brazil. Mimeo. Netherlands Soil Survey Institute at Wageningen, Netherlands. (Spanish version available as Informe no. 3677 from the Centro Interamericano de Fotointerpretación (CIAF), Bogotá, Colombia.)

FAO. 1974. Soil survey in irrigation investigation. Soils Bulletin (draft). FAO, Rome.

FAO. 1975. Land evaluation in Europe. Soils Bulletin 29. FAO, Rome.

FAO. 1976. A framework for land evaluation. Soils Bulletin 32. FAO, Rome.

Gibbons, F. R., and Y. C. F. M. Haans. 1976. Dutch and Victorian approaches to land appraisal. Soil Survey Paper No. 11. Neth. Soil Survey Institute, Wageningen, Netherlands.

Kellogg, C. E. 1961. Soil interpretation in the soil survey. U.S. Dept. Agric., Soil Conservation Service, Washington, DC.

Lemos, R. Costa de et al. 1960. Levantamento de reconhecimento dos solos do estado de São Paulo. Ministério da Agricultura, Conselho Nacional de Pesquisas, Commisão dos Solos, Rio de Janeiro.

Risseeuw, I. A. 1972. Relaciones entre la permeabilidad, la salinidad y la vegetacian natural de 15.000 ha de la zona norte de las Marismas de Hinojas (Huelos) y Arnalcazar (Servilla). (In Spanish). FAO Project AGL: SF/SPA 16, Internal Report.

Vink, A. P. A. 1975. Land use in advancing agriculture. Springer-Verlag, Berlin-Heidelberg.

Wind, G. P. 1976. Application of analog and numerical models to investigate the influence of drainage on workability in spring. Neth. J. of Agric. Sci. 24(3):155–172.

Wind, G. P. 1979. Analog modeling of transient moisture flow in unsaturated soil. PUDOC, Wageningen, The Netherlands.

Wit, C. T. de, and J. Goudriaan. 1974. Simulation of ecological processes. Simulation Monographs, PUDOC, ISBN 9022005097. Wageningen, Netherlands.

APPENDIX I

Bennema, J., K. J. Beek, and M. Camargo. 1964. Soil survey interpretation for reconnaissance surveys in Brazil. Mimeo. Netherlands Soil Survey Institute at Wageningen, Netherlands. (Spanish version available as Informe no. 3677 from the Centro Interamericano de Fotointerpretación (CIAF), Bogotá, Colombia.)

FAO. 1974. Soil survey in irrigation investigations. Soils Bulletin (draft). FAO, Rome. (Examples of USBR land classification specifications.)

Kevie, W. van der (ed). 1976. Manual for land suitability classification for agriculture. Part II. Guidelines for soil survey party chiefs. Soil Survey Administration, Wad, Medani (Sudan).

Laperre, R. 1976. A system of land suitability classification for irrigated sugar cane. Draft mimeo. Nairobi, Kenya.

Melitz, P. J., and R. Brinkman. 1975. Some land utilization types in Surinam; criteria for land suitability classification. Internal report, Soil Survey Inst., Paramaribo, Surinam.

Soepratohardjo, M., and G. H. Robinson. 1975. A proposed land capability appraisal system for agricultural uses in Indonesia. No. 9/1975. FAO Soil Research Inst., Bogor, Indonesia.

Role of the Soil Survey in Trace Element Studies

J. Kubota

To some, giving consideration to trace elements at a Soil Resources Inventory Workshop directed towards developing countries may appear to be an exercise in futility, in view of the magnitude of problems in developing viable programs. Trace element studies portray an image of sophisticated laboratories and work on problems that emerge as management practices are intensified to attain higher yields.

In retrospect, many historically unproductive areas have been made productive as problems of trace element deficiencies or toxicities have been overcome. The best example is Australia. Here, broad expanses of land were considered destined forever as "inherently infertile." The transformation of such areas to productive croplands has been dramatic, often with only a few ounces or pounds of a trace element (Anderson and Underwood, 1959). Applying a few ounces of molybdenum with nitrogen and phosphorus to land earlier vegetated by harsh native scrub plants has created lush pastures. A significant fact was that the potential of lands "inherently infertile" greatly exceeded acreages then in cropland.

In the United States, a historical note is also evident in the case of cobalt deficiency. Early settlers in parts of the New England states lived with a problem of poor livestock production. Before its association with cobalt deficiency, this poor productivity was attributed to a curse placed by Indian chief Chocurua on the white settlers for the death of his son (Keener, Percival, and Morrow, 1954). Similarly, selenium toxicity has been an endemic animal nutrition problem in parts of the U.S. This fatal disease among cavalry horses was first described in 1857 by an Army veterinarian in the Nebraska Territory (Anderson, 1961, p. 2). Earlier yet, it seems likely that Marco Polo encountered the same problem as he led his animal caravan to China. Numerous other examples are cited by Beeson (1941).

Such historical reviews emphasize a need to identify factors associated with poor agricultural productivity. Trace element problems are soil-related and their recognition can lead to productive land use. Recognition of specific soil characteristics associated with specific trace element problems is essential. Information applicable to assessment of potential trace element problems is often collected when soils are studied and mapped.

GENERAL CONSIDERATIONS

There are a number of trace elements that affect plant growth and a number that affect animals through the plants they ingest. Some, like An, Cu, Fe, and Mn, are essential to

both plants and animals; others like B primarily affect plant growth; still others like Co, I, and Se are essential to animals (with the exception that Co is essential for legumes). Then, there is an element like Mo that is essential to plants but, if present in exceedingly low or high concentrations in forages, also affects the animal. In ruminants, Cu utilization is affected by Mo.

The list of trace elements important to animals and man has increased with the recognition that Cr and Ni are essential to animals. The importance of some like Cd, Pb, and Hg has also become widely recognized because of their detrimental effects on environmental quality.

Soil-plant systems are important because most trace elements move in a food-and-feed chain from soils to plants to animals. Atmospheric pathways are important for some elements like I that are volatile and return to land surfaces in rainwater.

Most trace element problems result from an interaction of soil and plant factors that either enhance or depress trace element absorption by plants. Nutritional problems in animals arise largely because their trace element requirements and tolerances differ from those of the plants. Meeting plant requirements consequently does not necessarily meet the requirements of the animal. A wide range of problems exists and soil survey principles can be applied to their identification as well as to their solution.

ROLE OF SOILS IN NUTRITIONAL PROBLEMS OF ANIMALS SELECTED EXAMPLES

Some pertinent soil characteristics associated with four trace element problems in animal nutrition are presented (Table 1). Factors that affect the trace element concentration of plants are identified using forages as a common plant.

Cobalt

Cobalt is a trace element essential to ruminant animals for the production of vitamin B_{12}. Without adequate Co, animals suffer from a deficiency of vitamin B_{12}, a wasting disease. A minimum of 0.04 to 0.07 ppm of Co is needed in forage plants to meet animal requirements. Humaquods of sand texture are a common example of soils that produce Co-deficient forages in the U.S. Recognition of these soils largely defines the geographic extent of the problem areas. Humaquods on the lower Atlantic coastal plains in particular have small amounts of Co (about 1 ppm total). The low Co content of soils reflects low levels inherited from the sandy coastal plain deposits, which have undergone one or more cycles of weathering prior to their transport and deposition. The consequences of these inherited low Co levels in Humaquods are accentuated by leaching losses.

Molybdenum

In the case of Mo, animals suffer from molybdenosis when Mo exceeds 10 to 20 ppm in forage plants. Supplemental Cu, either through injection or feeding of mineral supplements enriched with Cu, counteracts the effect of excess Mo. Molybdenosis consequently is recognized as cases of Mo-induced Cu deficiencies. Soil wetness, neutral to alkaline soil reactions, and Mo-rich soil parent materials are interrelated factors that enhance the production of Mo-toxic forage plants. Alluvial fans and floodplains of small streams are likely problem areas because they are landscapes where Mo-rich

Table 1. Soil characteristics and soil parent material interactions associated with nutritional problem areas for animals in the U.S.

Trace element	Nutritional problem-animals	Significant plant conc.	Principal characteristics	
			Soil	Soil parent material
Cobalt	Deficiency	0.04 to 0.07 ppm or less	Sand texture, acid, poor drainage (Humaquods)	Coastal plain dep.; glacial drift-White Mtn granite
Molybdenum	Toxicity	10 to 20 ppm or more	Poor drainage, neutral to alkaline reaction	Granitic alluvium; alluvium from shale
Selenium	Toxicity	4 to 5 ppm or more	Alkaline reaction, calcareous, good drainage	Seleniferous rocks, Cretaceous shales
	Deficiency	0.05 ppm or less	Acid reaction	Mixed, nonseleniferous deposits
			Neutral to alkaline	Volcanic ash
Magnesium	Deficiency	0.15% or less (?)	Mesic soil zone; limited available soil moisture	Mixed, unconsolidated deposits, volcanic ash
	Adequate	0.20% or more	Mesic soil zone	Dolomitic till; weathered serpentinite
			Thermic soil zone	(except coastal plain)

alluvium is deposited essentially undiluted with low Mo materials from other stream sources. Molybdenosis is not a problem on floodplains of major rivers.

Forage crops with exceedingly low Mo and high Cu have been implicated in cases of Cu-induced Mo deficiencies. Naturally occurring areas are recognized in Australia but the problem has not been clearly identified in the U.S.

Selenium

Selenium is implicated in both animal deficiencies and toxicities in the U.S. White Muscle disease in cattle and sheep is a common Se-responsive disease. Deficiencies result when selenium levels in forages fall below 0.05 ppm. The development of acid soils on soil parent material with low to moderate Se levels is a contributing factor in disease incidence.

The Se-toxic areas for animals are nearly always associated with the development of well-drained, neutral to alkaline, calcareous soils formed on Se-rich soil parent materials. Cretaceous shale is often the seleniferous rock associated with Se-toxic areas. The growing of Se-accumulator plants like certain species of *Astragalus* and *Stanleya* on seleniferous soils accentuates the movement of Se from soils to plants and enhances incidences of Se toxicity in animals.

Magnesium

Grass tetany is a conditioned Mg deficiency that is a widespread nutritional disease in cattle in the U.S. and elsewhere. A high incidence in the midlatitude states implicates temperature. With adequate moisture, grasses grown under warm temperature take up more Mg than grasses grown under cooler temperatures. The role of warm temperature is evident in grasses from the Piedmont region of the southeastern U.S. (thermic soil zone). Soils here are highly leached and have low Mg status (exchangeable soil Mg) but the grasses have as much Mg as they do where grown on soils formed in dolomitic till in Wisconsin, Illinois, Minnesota, and Iowa. A high turnover rate of soil Mg probably is important in the Ultisols, and a large Mg reserve in Alfisols formed in dolomitic till.

The production of forage plants with deficient, adequate, or toxic trace element levels reflects an interplay of several soil factors. Soil parent material is an important component in nearly all cases because it largely establishes the soil capacity for sustained trace element release to plants. Soil weathering largely activates this release and thus serves as an intensity factor. Together they govern the availability status of soil trace elements. The effect of the two components can be measured using plants as a bioassay tool.

Most soils in the U.S. are formed in unconsolidated surficial deposits. An assessment of kinds of surficial deposits is useful. Comparisons of Mo in glacial deposits of the north-central states, for example, indicate that outwash has less Mo and loess and lacustrine deposits more Mo than does glacial till associated with them. Clay soils also have appreciable amounts of Co and plants grown on such soils have adequate Co.

APPLICATION OF SOIL SURVEY

Principles of the soil survey can be selectively applied with principles of soil chemistry and mineral nutrition of plants in the understanding of soil trace element behavior. Essential features from these disciplines can be used to account for the biological activity of trace elements in soils and their absorption by plants. Water-soluble forms of mineral elements are available for plant absorption. In humid regions they are subject to leaching losses; in dry land areas, their role would be dependent on available soil moisture supply.

Planning stage

Conceptual models of soils associated with a trace element problem can be developed through literature review and field observations. The development of a working soil model provides a basis to account for low, adequate, or high trace element concentrations in plants. Poor plant growth is a poor indicator of excesses or deficiencies of trace elements in forage plants fed the animals.

Selection of sites

Careful selection of real soils using models of problem soils greatly enhances the selection of sites to study. The geographic distribution pattern of problem areas is often obscure in the initial phases of studies and the problem areas may be quite localized, occupying only parts of the landscape. The kinds of soils available for study are almost unlimited (over 12,000 soil series) and judicious selection of sites is essential. In most cases sampling errors override magnitude of analytical errors.

Soil maps when available can be used to locate specific soil sites for study. In areas where soil maps are not available general knowledge of geology, soils, and animal observation can be used to good advantage.

The validity of soil models can be tested with data from a relatively few, carefully selected sites. The model of problem soils can be modified as data become available. A necessary component for such evaluations would be the availability of complete soil descriptions.

Collection of soil profile samples

As a study develops, a need for a better understanding of trace element distribution and behavior in soils through laboratory studies may become evident. Where initial phases of the study are tied closely to soil, they enhance the collection of soil profile samples. For example, a need arose to study the distribution of Co in southeastern coastal plain soils. Cobalt deficiency appeared to be confined principally to areas of Humaquods and its absence from area of Ultisols was striking. Determinations of acetic acid and dithionite-extractable Co together with total Co showed that much more of the total Co was in extractable form in Ultisols than in Humaquods (Kubota, 1965). While not linear, the larger amounts of extractable Co were reflected in higher Co concentrations in plants.

DISCUSSION

Successful use has been made of soil survey principles in cooperative trace element studies by the Soil Survey Investigations, Soil Conservation Service, and the U.S. Plant, Soil and Nutrition Laboratory, Agric. Research Service. The inclusion of a soil survey in the planning stage provides a means to prepare subsequent maps that depict the geographic distribution of trace element problems. Principles of soil weathering and soil chemistry have many common features and both can be applied in the understanding of trace element behavior in soils.

The study of molybdenum-toxic areas illustrates how soil survey principles were applied, in a series of studies, to solve a trace element problem in the western states. The first study was initiated in Nevada in the late 1950's. Molybdenosis was suspected but the role of soils and factors associated with them was not defined. Results from relatively few carefully selected sites the first year clearly implicated wet parts of granitic alluvial fans. As much as 400 ppm of molybdenum was found in legumes, well above toxic levels of 10 to 20 ppm. Results of the following year showed that granitic alluvial fans differed widely with respect to molybdenum (Table 2) and only some of them were implicated (Kubota et al., 1961).

An interaction of soil parent material molybdenum and soil wetness was implicated. The role of soil wetness in increasing molybdenum concentration was verified by growing plants under controlled wetness in the greenhouse (Kubota, Lemon, and Allaway, 1963). The excessively drained Mottsville soil (sandy, mixed, mesic Torripsammentic Haploxerolls) and its poorly drained associate, the Ophir soil (sandy, mixed, mesic Typic Haplaquolls) responded similarly when subjected to similar soil wetness conditions (Figure 1).

The model was then tested in Baker Valley, Oregon. Here, narrow floodplains of six tributary streams, all of the Powder River, were investigated (Kubota et al., 1967). As much as 4.3 ppm of molybdenum was found in the wet soil (mostly Aquepts) of Hot

Table 2. Molybdenum in legumes from seven granitic alluvial fans—Nevada.

Fan	Molybdenum[a] Alfalfa	Molybdenum[a] Clover
	(ppm)	(ppm)
	Carson Valley	
I	—	16
II	23	76
III	241	315
IV	114	175
	Washoe Valley	
V	14	22
VI	7	11
VII	6	5

[a]Means of several samples.

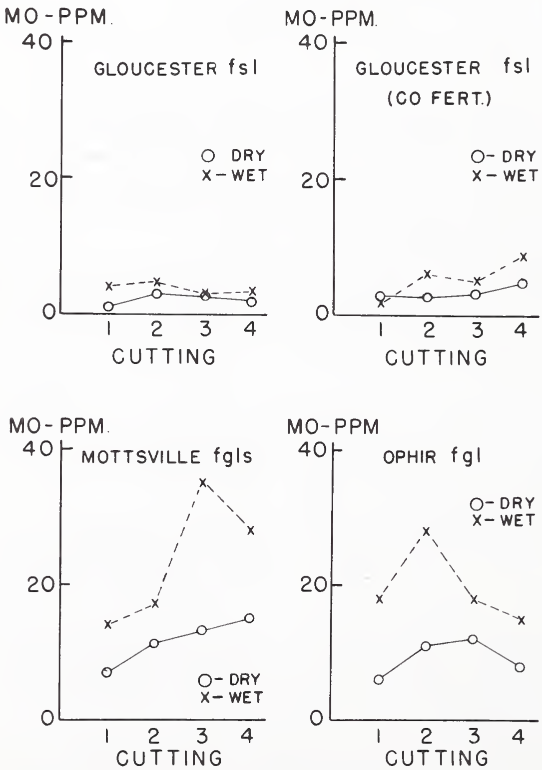


Figure 1. The effect of moisture treatments upon the molybdenum content of alsike clover.

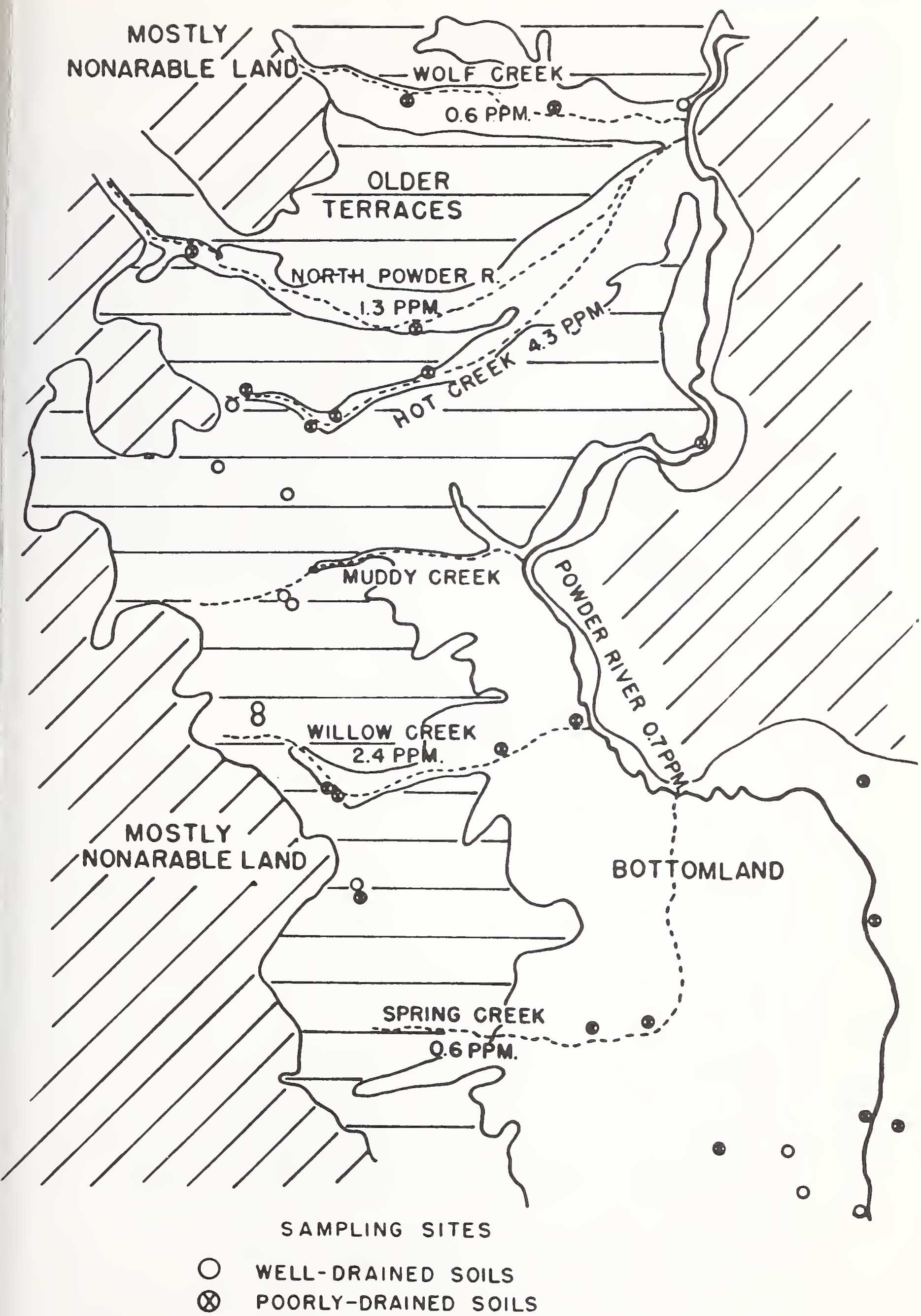


Figure 2. Molybdenum content of soils in Baker Valley, Oregon, in relation to tributary stream sources.

Creek compared with 0.6 ppm in morphologically similar soils of Wolf Creek and Spring Creek (Figure 2). The soil molybdenum concentration was reflected in plant concentration (Figure 3). Similar plants from well-drained soils had uniformly small amounts of molybdenum.

Possibilities of molybdenum-toxic areas in other western states were investigated, focusing on livestock production areas where physiography, bedrock, and soils were similar. Several areas previously not associated with molybdenosis were identified (Kubota, 1975) in Washington, Montana, Idaho, Wyoming, and Colorado.

Observations of plant molybdenum concentrations in the western states combined with those of the eastern states (Kubota, 1977) provided the basis to prepare the plant molybdenum map of the U.S. (Figure 4). Effects of soil molybdenum availability are reflected in the decreasing plant molybdenum concentration from west to east.

Principles for sampling soils for trace element studies have been presented (Kubota, 1972) as have their application to study the geographic distribution of trace element problems in the U.S. (Kubota and Allaway, 1972).

Recognition of soil temperature and soil moisture regimes is useful when plant response to trace elements in soils is assessed. Lack of soil moisture may be the limiting factor rather than an absence of available forms of soil trace elements to plants. They also provide a means to account for differences in plant concentrations observed under field conditions and under carefully controlled conditions in a greenhouse or growth chamber study.

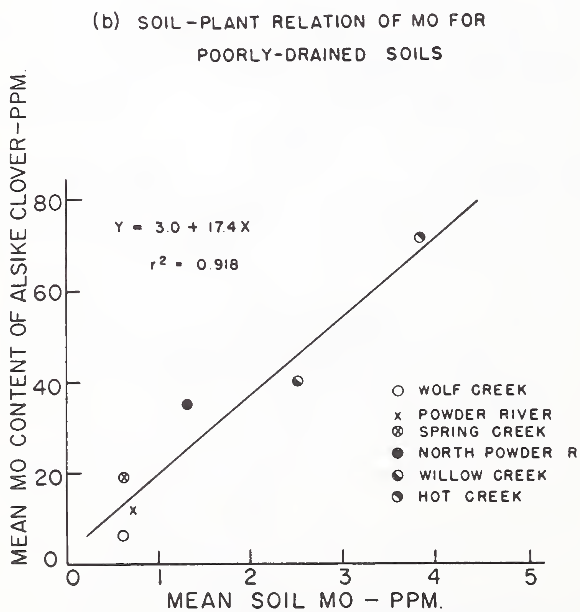
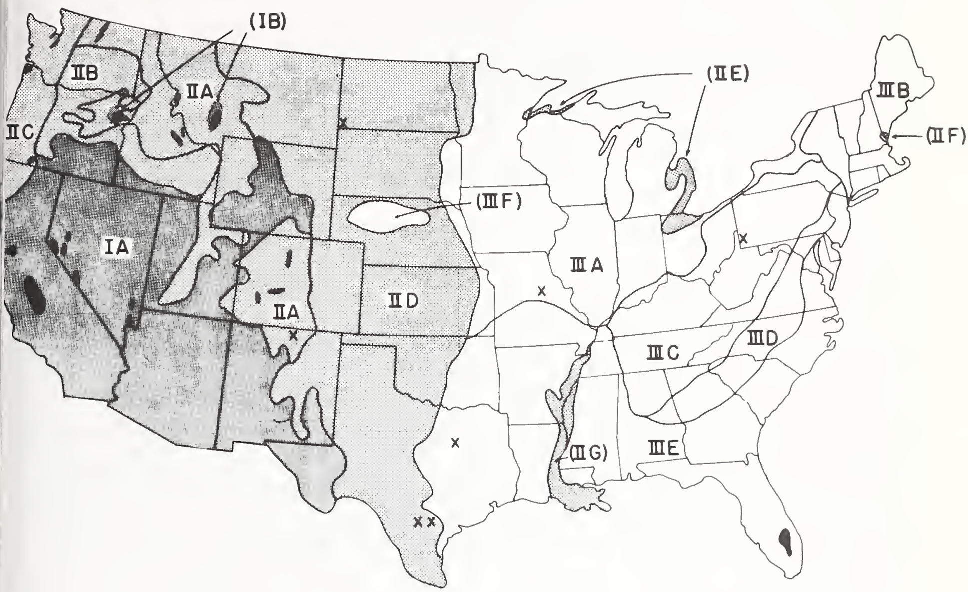


Figure 3. Molybdenum content of legumes in relation to soil molybdenum (total) in Ap horizons of poorly drained soils.



AREA	NUMBER OF SAMPLES	MEDIAN CONC.	FREQUENCY DISTRIBUTION (%) OF SAMPLES WITH Mo CONCENTRATIONS (ppm) OF :					
			<0.1 to 0.5	0.5 to 1	1 to 2	2 to 4	4 to 8	>8
IA	344	6	—	2	9	12	45	32
IB	79	8	0	0	3	19	24	54
II A	174	2	—	14	16	28	29	13
II B	174	3	—	8	14	42	32	4
II C	108	2	—	—	35	26	27	12
II D	34	2.6	6	12	24	26	21	11
II E	64	1.9	2	19	31	39	7	2
II F	10	3.2	0	0	30	50	10	10
II G	17	1.5	0	18	47	24	11	0
III A	201	0.4	54	23	14	7	2	0
III B	78	1.0	22	26	32	18	2	0
III C	37	0.3	74	16	5	5	0	0
III D	26	0.4	73	8	19	0	0	0
III E	41	0.4	51	25	22	2	0	0
III F	8	0.5	50	25	13	12	0	0

GENERAL LOCATION OF NATURALLY OCCURRING MOLYBDENUM-TOXIC AREAS

X GENERAL LOCATION OF INDUSTRIAL MOLYBDENOSIS

Figure 4. Geographic distribution of molybdenum concentration in legumes of the United States.

Sensitive analytical methods are continually being developed or adapted to meet the needs for soil-plant studies of trace elements. With increased, sensitive methods, a greater need arises to better select meaningful samples for laboratory study. Carefully planned studies based on soil surveys have greater predictive value than randomly collected samples.

Potential trace problems in plants and animals and their geographic distribution can be assessed as soil survey inventories are made. Their importance will increase as wider uses are made of soils for varied purposes.

LITERATURE CITED

Anderson, A. J., and E. J. Underwood. 1959. Trace element deserts. Sci. Am. 200:97–106.

Anderson, M. S. 1961. Selenium in agriculture. U.S. Dept. Agric. Handbook 200. U.S. Govt. Printing Office, Washington, DC 20402.

Beeson, K. C. 1941. The mineral composition of crops with particular reference to the soil in which they were grown. U.S. Dept. Agric. Misc. Publ. 369. U.S. Govt. Printing Office, Washington, DC 20402.

Keener, H. A., G. P. Percival, and K. S. Morrow. 1954. Cobalt deficiency in New Hampshire cattle, sheep and goats. New Hampshire Agric. Exp. Stn. Bull. 411.

Kubota, J. 1965. Distribution of total and extractable forms of cobalt in morphologically different soils of eastern United States. Soil Sci. 99:166–174.

Kubota, J. 1972. Sampling of soils for trace element studies. N.Y. Acad. Sci. Ann. 199:105–117.

Kubota, J. 1975. Areas of molybdenum toxicity to grazing animals in the western states. J. Range Manage. 28(4):252–256.

Kubota, J. 1977. Molybdenum status of U.S. soils and plants. p. 555–581. *In* W. Chappell and K. Peterson (ed.) The geochemistry, cycling and industrial uses of molybdenum. Vol II. Marcel Dekker, Inc., New York.

Kubota, J., and W. H. Allaway. 1972. Geographic distribution of trace elements problems in the United States. p. 525–554. *In* J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (ed.) Micronutrients in agriculture. Soil Sci. Soc. Am., Madison, WI.

Kubota, J., V. A. Lazar, L. N. Langan, and K. C. Beeson. 1961. The relationship of soils to molybdenum toxicity in cattle in Nevada. Soil Sci. Soc. Am. Proc. 25:227–232.

Kubota, J., V. A. Lazar, G. H. Simonson, and W. W. Hill. 1967. The relationship of soils to molybdenum toxicity in grazing animals in Oregon. Soil Sci. Soc. Am. Proc. 31:667–671.

Kubota, J., E. R., Lemon, and W. H. Allaway. 1963. The effect of soil moisture content upon the uptake of molybdenum, copper and cobalt by alsike clover. Soil Sci. Soc. Am. Proc. 27:679–683.

Soil Properties Important for Various Tropical Crops: Pahang Tenggara Master Planning Study

Richard Protz

The ultimate soil survey would be of a scale such that the rooting area is characterized for each plant. This is impossible to achieve for small crops because the concentration of soil observations during a survey would be so great that the surveyor would literally be creating a new soil. However, for the major tree crops a soil survey for each tree is possible. In areas of the world of very intensive land use, the farmers treat each tree as an individual and know the soil properties in sufficient detail.

In these areas the soil questions are: (1) which soil properties dominate growth, and (2) if the crop is grown on a different soil what changes in yield can be expected. These are two very important questions as people cultivate larger areas of less suitable soils.

OPERATIONAL ASPECTS OF THE PAHANG TENGGARA PROJECT

Soil survey

The soil science team had to survey 500,000+ acres on a ½ mile rentis interval with eight observations/mile (Pahang Tenggara Regional Master Planning Study, 1972). Each soil mapping unit had to be assessed as to its suitability for the production of any crop that might be grown.

To start with we had the economists and agronomists decide which crops could possibly be profitably grown in Pahang Tenggara given known agronomic techniques and world market conditions. They generated a list of approximately 40 crops (Table 1) from which we had the agronomists generate six characteristic rooting patterns. These six rooting patterns were given to the soil surveyors, the purpose being that the surveyors would note additional soil characteristics which would be useful for classifying each mapping unit for specific crops.

Soils criteria for crops

The soil management literature was reviewed for specific soil properties affecting each crop. Precious little information was available beyond the standard . . . this crop grows best on deep, well-drained, friable, highly fertile soil . . . Obviously, if a decision was to be reached on which crop had the best chance of economic success on the poorer soils, more specific soils criteria were required.

Table 1. Crops with an economic potential in Pahang Tenggara—clustered into groups with similar growing habits and requiring similar soil properties and soil management.

Crop Group	Crops in Group
A. Rubber Group	—Rubber
B. Oil Palm Group	—Oil Palm
C. Sago Group	—Sago Palm
D. Tapioca Group	—Tapioca, Sweet Potatoes, Soyabeans, Chillies, Vegetables
E. Tea Group	—Lowland Tea
F. Grass Group	—Stylo, Grasses (cut)
G. Citrus Group	—Citrus, Mangosteen, Chiku
H. Papaya Group	—Papaya, Pineapple, Passion Fruit, Guava, Salak
I. Banana Group	—Bananas, Durian, Rambutan, Langsat, Duku, Soursop, Jackfruit, Chempedak, Avocado, Kundangan
J. Cashew Group	—Cashew
K. Cocoa Group	—Cocoa, Coffee
L. Coconut Group	—Coconut
M. Maize Group	—Maize, Sorghum, Groundnuts
N. Rice Group	—Lowland Rice

We decided on ten soil properties which were important to crop growth and which were mappable ("uniform"—within soil mapping units). These properties are shown in Table 2. From the literature limits were projected on each of the ten soil properties for each crop. The Malaysian agronomists and soil scientists were consulted and their ideas were incorporated; the criteria are shown in Table 3.

Creation of a crop suitability map

Upon completion of the soil survey map, Soil Capability Performance Groups were tabulated. The Soil Capability Performance Groups are subdivisions of the soil capability subclasses and are collections of soil mapping units, or single mapping units that have comparable potential productivity and need similar management to maintain or improve their level of productivity. On the basis of this concept the soil mapping units were condensed into a shorter list of Soil Performance Groups and each of these were classified for each crop group (Table 4).

From Table 4 and the soil maps a summary of the acreages available for each crop group by each soil capability class was developed (Table 5). Then a crop suitability map was generated. The project economists and planners were given the number of acres and the distribution of those acres for each crop group. Thus the economists and planners could now calculate all possible alternative crop combinations depending upon location and economic criteria.

Table 2. List of ten soil properties and reasons for their choice.

Soil Properties	Reason Chosen
1. Slope	—mappable, important from mechanization and conservation viewpoints.
2. Effective soil depth	—mappable, important for root penetration, nutrient and water holding capacity.
3. Soil texture—structure	—mappable, important for water release, workability, aeration and root penetration
4. Drainage	—mappable, important for mechanization, aeration, water supply.
5. Water release	—mappable from texture and structure, important for crop water uptake.
6. Salinity	—can be approximated for soil series, important for plant growth.
7. pH	—can be approximated for soil series, important in fertility, minor element deficiencies, toxicity effects of certain elements, plant disease resistance and liming requirements.
8. Depth to acid sulfate	—mappable, important due to effects on pH, salt concentration, and root penetration.
9. Thickness of peat	—mappable, important for mechanization, tree crop stands and shrinkage.
10. Workability	—mappable, important for cultivation of annuals and certain tree crops.

CONCLUSIONS

The need for the Soil Capability Performance Groups remains a question. It seems we could easily go from the soil mapping units through to the soil capability subclasses directly to the crop suitability tables and maps. Wong (1974) has made this shortcut.

I question if we should spend any more effort on ... deep, well-drained, friable, highly fertile soils ... There is a greater need for knowledge on Soil Capability classes III and IV in countries with present low food production.

LITERATURE CITED

Pahang Tenggara Regional Master Planning Study. 1972. Soil Survey Studies and Investigations. The Government of Malaysia.

Wong, I. F. T. 1974. Soil—Crop Suitability Classification for Peninsular Malaysia. Ministry of Agriculture and Fisheries, Malaysia.

Table 3. Major criteria used in assessing the soil suitability for crops.

Crop Group / Crop	Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat (drained)	Workability
				Soil Criteria						
A. Rubber										
Rubber	0–20°	>125 cm	Exclude LS or coarser	Exclude poorly drained	All Year	<2 mmhos in top 150 cm	4.0–6.0	>150 cm	<50 cm	N.I.[a]
B. Oil Palm										
Oil Palm	0–16°	>125 cm	Exclude SL or coarser	Some temporarily poorly drained	All year	<2 mmhos in top 150 cm	4.0–6.5	>100 cm	<100 cm	N.I.
C. Sago Palm										
Sago Palm	0–2°	>100 cm	Exclude SL or coarser	Very poorly to poorly only	—	<2 mmhos in top 150 cm	4.0–6.0	>125 cm	<50 cm	N.I.
D. Tapioca										
Tapioca	0–6°	>50 cm	Exclude clays and poor structures	Exclude poorly drained	All year	<2 mmhos in top 100 cm	4.3–7.3	>50 cm	No restriction	No restrictions allowed
Sweet Potatoes	0–6°	>50 cm	Exclude clays and poor structures	Exclude poorly drained	All year	<2 mmhos in top 100 cm	4.3–6.0	>50 cm	No restriction	No restrictions allowed
Soyabeans	0–6°	>25 cm	Exclude clays and poor structures	Well to imperfectly only	Growing season	<4 mmhos in top 50 cm	5.5–6.5	>50 cm	<25 cm	No restrictions allowed
Chillies	0–6°	>25 cm	Exclude clays and poor structures	Well to imperfectly	Growing season	<4 mmhos in top 50 cm	5.0–6.8	>50 cm	<25 cm	No restrictions allowed
Vegetables	0–6°	>25 cm	Exclude clays and poor structures	Well to imperfectly	Growing season	<4 mmhos in top 50 cm	4.5–6.5	>50 cm	No restriction	No restrictions allowed
E. Tea										
Lowland Tea	0–20°	>100 cm	Exclude sands, clays	Well to imperfectly	All Year	<2 mmhos in top 150 cm	4.0–6.0	>25 cm	No peat	N.I.
F. Grass										
Grasses (Cut)	0–12°	>25 cm	Exclude LS and coarser	Well to poorly	All year	<4 mmhos in top 50 cm	4.3–7.0	>50 cm	No restriction	No restrictions allowed
Stylo	0–12°	>25 cm	Exclude sands	Well to poorly	All year	<4 mmhos in top 50 cm	4.3–7.0	>50 cm	Not known	No restrictions allowed

Crop Group / Crop	Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat (drained)	Workability
	Soil Criteria									
G. Citrus										
Citrus	0–20°	>125 cm	Exclude sands and heavy clays	Well, some imperfectly	All year	<2 mmhos in top 150 cm	5.0–7.0	>150 cm	<50 cm	No stones
Chiku	0–20°	>125 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	Not known	>150 cm	<50 cm	No stones
Mangosteen	0–20°	>125 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	Not known	>150 cm	<50 cm	No stones
H. Papaya										
Papaya	0–12°	>50 cm	Exclude LS or coarser	Well to imperfectly	All year	>2 mmhos in top 100 cm	5.0–6.5	<100 cm	No peat	No stones
Pineapple	0–6°	>25 cm	All textures	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–5.5	>50 cm	No restriction	No stones
Passion fruit	0–12°	>50 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<50 cm	No stones
Guava	0–12°	>50 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<100 cm	No stones
Salak	0–12°	>50 cm	Exclude LS or coarser	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	No stones
I. Bananas										
Bananas	0–12°	>125 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	5.0–7.0	>125 cm	<25 cm	No stones
Durian	0–12°	>100 cm	Exclude LS or coarser; firm soils; oxisolic soils	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	No peat	N.I.
Rambutan	0–12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<100 cm	No stones
Langast	0–12°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N.I.
Duku	0–12°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N.I.

Table 3. Cont.

Crop Group / Crop	Soil Criteria: Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat (drained)	Workability
Soursop	0–6°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N.I.
Jackfruit	0–12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<100 cm	No stones
Chempedak	0–12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N.I.
Avocado	0–12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 150 cm	5.5–6.5	>125 cm	No peat	N.I.
Kundangan	0–12°	>100 cm	Exclude clays	Well drained	All year	<2 mmhos in top 150 cm	Not known	>125 cm	No peat	N.I.
J. Cashew										
Cashew	0–20°	>100 cm	Exclude clays	Well to imperfectly	9 months	<2 mmhos in top 150 cm	4.0–7.3	>150 cm	<100 cm	N.I.
K. Cocoa										
Cocoa	0–12°	>150 cm	Exclude LS or coarser	Well to imperfectly	High all year	<2 mmhos in top 150 cm	5.0–7.5	>150 cm	<50 cm	N.I.
Coffee	0–12°	>125 cm	Exclude sands	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.5–6.5	>100 cm	<125 cm	N.I.
L. Coconut										
Coconut	0–6°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.5–7.5	>100 cm	<100 cm	N.I.

					Soil Criteria					
Crop Group Crop	Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat (drained)	Workability
M. Maize										
Maize	0–6°	>50 cm	Exclude sands and clays	Well to imperfectly	Good in growing season	<2 mmhos in top 50 cm	>5.0	>125 cm	No restriction	No restrictions allowed
Sorghum	0–6°	>50 cm	Exclude sands	Well to imperfectly	Good in growing season	<4 mmhos in top 50 cm	>5.0	>125 cm	No restriction	No restrictions allowed
Groundnut	0–6°	>25 cm	Exclude sands and clays	Well to moderately well	Good in growing season	<4 mmhos in top 50 cm	5.5–7.0	>50 cm	No peat	No restrictions allowed
N. Rice										
Lowland Rice	0–2°	>25 cm	SCL or finer	Drainage control necessary	Dry during harvest	<4 mmhos in top 25 cm	>4.0	>25 cm	No peat	No restrictions allowed

[a]N.I.—Not important.

Table 4. Crop Suitability According to Soil Performance Groups[a]

Soil Performance[c] Group	Acreage	A Rubber	B Oil Palm	C Sago	D Tapioca	E Tea	F Grass	G Citrus	H Papaya	I Banana	J Cashew	K Cocoa	L Coconut	M Maize	N Rice
							Crop Groups								
					SOIL CAPABILITY CLASS I										
I-^{1}	790	W[b]	W	U[b]	W	S[b]	W	W	W	W	S	S	W	W	U
I-^{2}	570	W	W	U	W	W	W	W	W	W	S	W	W	W	U
I-^{3}	390	W	W	U	W	W	W	W	W	W	S	W	W	W	U
I-^{4}	7,920	W	W	U	W	W	W	W	W	W	W	S	W	W	U
IEn-^{1}	43,410	W	W	U	W	W	W	W	W	W	S	W	S	W	U
IEn^{2}	1,740	W	W	U	S	W	W	W	W	W	S	W	S	S	U
IEn-^{3}	1,230	W	W	U	S	W	W	W	W	W	S	W	M[b]	S	U
IEn-^{4}	22,560	W	W	U	W	W	W	W	W	W	S	S	M	W	U
IEn-^{5}	12,210	W	W	U	W	W	W	W	W	W	W	S	S	W	U
IEn-^{6}	1,060	W	S	U	U	W	M	W	S	W	S	W	U	U	U
IEn-^{7}	740	W	S	U	U	W	M	W	S	W	S	W	U	U	U
IDPn-^{1}	3,260	W	W	U	W	W	W	W	W	W	W	W	W	W	U
IDPn-^{2}	9,170	W	W	U	W	W	W	S	W	W	W	S	W	W	U
IDPn-^{3}	6,540	S	S	U	W	S	S	S	S	S	W	M	S	W	U
IDPn-^{4}	1,570	W	W	U	W	W	W	S	W	W	W	S	S	W	U
IDPn-^{5}	8,330	S	S	U	W	S	W	S	W	W	W	M	W	W	U

Soil Performance[c] Group	Acreage	Crop Groups													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
		Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
SOIL CAPABILITY CLASS II															
IIEm^{-1} . .	47,750	W	S	U	U	W	M	W	M	W	S	W	U	U	U
IIEm^{-2} . .	27,020	W	S	U	U	W	M	W	M	W	S	W	U	U	U
IIEm^{-3} . .	1,640	W	S	U	U	W	M	S	M	W	W	S	U	U	U
IIEm^{-4} . .	770	S	M	U	U	S	U	S	U	U	S	M	U	U	U
IIDmEPn^{-1} . .	2,440	S	S	U	S	S	S	S	M	S	W	U	M	S	U
IIDm^{-1} . .	26,950	M	M	W	U	U	S	U	S	U	U	U	M	S	W
IIDm^{-2} . .	15,130	M	M	W	U	U	S	U	S	U	U	U	S	S	S
IIPmEn^{-1} . .	4,110	W	W	U	S	W	W	S	W	S	S	M	M	W	U
IIPmEn^{-2} . .	2,600	W	S	U	M	S	W	M	S	M	U	U	U	S	U
IIPmEn^{-3} . .	2,800	W	S	U	M	S	W	M	S	M	U	U	U	S	U
IICmEn^{-1} . .	5,490	W	W	U	W	W	W	W	W	S	S	S	M	W	U
IICmEn^{-2} . .	1,820	W	W	U	S	W	W	W	W	W	M	S	M	W	U
IICmEn^{-3} . .	10,000	W	W	U	S	W	W	W	W	S	S	S	M	W	U
IICmEn^{-4} . .	870	W	S	U	W	W	W	W	W	S	W	S	S	W	U
IICmEn^{-5} . .	1,110	W	S	U	S	W	W	S	W	M	S	M	U	W	U
IICmEn^{-6} . .	3,870	W	S	U	S	W	W	S	S	S	S	M	U	W	U
IICmEn^{-7} . .	690	S	M	U	U	S	W	M	S	U	U	U	U	S	U
IICmEn^{-8} . .	660	S	M	U	U	S	W	M	S	U	U	U	U	S	U
IICmEn^{-9} . .	4,670	S	M	U	M	S	W	M	M	U	S	U	U	S	U
IICmEn^{-10} . .	1,990	W	M	U	U	W	M	S	M	M	S	M	U	U	U

Table 4. Cont.

Soil Performance[c] Group	Acreage	Crop Groups A Rubber	B Oil Palm	C Sago	D Tapioca	E Tea	F Grass	G Citrus	H Papaya	I Banana	J Cashew	K Cocoa	L Coconut	M Maize	N Rice
SOIL CAPABILITY CLASS III															
IIIEs^{-1} . .	6,410	S	M	U	U	S	U	M	U	U	M	M	U	U	U
IIIEs^{-2} . .	5,190	S	M	U	U	S	U	M	U	U	M	U	U	U	U
IIIEPm^{-1} . .	3,330	S	M	U	U	M	M	M	M	M	U	U	U	U	U
IIIEPm^{-2} . .	790	S	M	U	U	U	M	U	M	U	U	U	U	U	U
IIIEPm^{-3} . .	2,960	S	M	U	U	U	M	U	U	U	U	U	U	U	U
IIIPs^{-1}	9,690	M	U	U	U	U	S	U	M	U	U	U	M	M	M
IIICEm^{-1} . .	4,760	W	S	U	U	W	M	S	M	S	S	S	U	U	U
IIICEm^{-2} . .	1,630	S	M	U	U	S	M	M	M	U	M	M	U	U	U
IIICEm^{-3} . .	8,610	W	S	U	U	W	M	S	M	S	S	M	U	U	U
IIICEm^{-4} . .	500	S	M	U	U	M	M	U	M	U	U	U	U	U	U
IIICEm^{-5} . .	7,140	S	M	U	U	S	M	M	M	U	M	U	U	U	U
IIICEm^{-6} . .	1,470	S	M	U	U	U	M	U	M	U	U	U	U	U	U
IIICEm^{-7} . .	1,630	S	M	U	U	U	M	U	M	U	U	U	U	U	U
IIICEm^{-8} . .	1,910	S	U	U	U	U	M	U	M	U	U	U	U	U	U
IIICEm^{-9} . .	2,900	S	M	U	U	M	M	U	M	U	M	U	U	U	U
IIICEm^{-10} . .	350	S	U	U	U	M	U	U	U	U	U	U	U	U	U
IIICs^{-1} . .	980	S	M	U	U	S	W	M	S	M	M	M	U	M	U
IIICs^{-2} . .	4,250	S	M	U	U	S	W	M	S	M	M	M	U	M	U
IIICs^{-3} . .	1,290	S	M	U	U	M	W	U	M	U	M	U	U	M	U
IIICsEm^{-1} . .	1,280	S	M	U	U	S	M	M	M	M	M	M	U	U	U

Soil Performance[c] Group	Acreage	A Rubber	B Oil Palm	C Sago	D Tapioca	E Tea	F Grass	G Citrus	H Papaya	I Banana	J Cashew	K Cocoa	L Coconut	M Maize	N Rice
								Crop Groups							
SOIL CAPABILITY CLASS III—*(cont.)*															
IIICsEm-^{2} ..	1,800	S	M	U	U	S	M	M	M	U	M	U	U	U	U
IIICsVm-^{1} ..	2,390	S	M	U	U	M	W	U	M	U	M	U	U	M	U
IIICsVm-^{2} ..	7,480	M	U	U	U	M	S	U	M	U	M	U	U	M	U
IIICsVm-^{3} ..	6,960	M	U	U	U	U	M	U	U	U	U	U	U	U	U
IIIDs-^{1} ..	20,440	M	M	S	U	U	S	U	M	U	U	U	S	U	S
IIIDs-^{2} ..	12,520	M	M	U	M	U	S	U	M	M	M	U	M	M	M
SOIL CAPABILITY CLASS IV															
IVEPs-^{1} ..	870	S	M	U	U	M	U	M	U	U	U	U	U	U	U
IVEPs-^{2} ..	760	S	U	U	U	U	U	U	U	U	U	U	U	U	U
IVEPs-^{3} ..	1,570	S	U	U	U	U	U	U	U	U	U	U	U	U	U
IVCEs-^{1} ..	1,520	S	M	U	U	S	U	M	U	U	S	U	U	U	U
IVCEs-^{2} ..	9,890	S	U	U	U	S	U	U	U	U	S	U	U	U	U
IVCEs-^{3} ..	630	M	U	U	U	U	U	U	U	U	U	U	U	U	U
IVCEs-^{4} ..	6,480	M	U	U	U	U	U	U	U	U	U	U	U	U	U
IVCVsEm-^{1} ..	1,120	S	U	U	U	U	M	U	U	U	M	U	U	U	U
IVCVsEm-^{2} ..	8,320	M	U	U	U	U	M	U	U	U	U	U	U	U	U
IVCVsEm-^{3} ..	6,370	M	U	U	U	U	M	U	U	U	U	U	U	U	U
IVDOs-^{1} ..	360	U	U	W	U	U	U	U	M	U	U	U	M	U	S
IVDOs-^{2} ..	3,320	U	U	U	U	U	U	U	U	U	U	U	U	U	U

Table 4. Cont.

Soil Performance[c] Group		Acreage	A Rubber	B Oil Palm	C Sago	D Tapioca	E Tea	F Grass	G Citrus	H Papaya	I Banana	J Cashew	K Cocoa	L Coconut	M Maize	N Rice
									Crop Groups							
SOIL CAPABILITY CLASS V																
VCvEVs-^{1}	..	3,160	M	U	U	U	U	U	U	U	U	U	U	U	U	U
VCvEVs-^{2}	..	2,800	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VCvEVs-^{3}	..	1,320	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VCvEvs-^{4}	..	3,880	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VOv-^{1}	..	61,350	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VEv-^{1} ..	..	46,970	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VIIvEs-^{1}	..	60	U	U	U	U	U	U	U	U	U	U	U	U	U	U
		561,145														

[a]Assumptions used in rating soil capability performance groups:

1. It is assumed that crops will be grown with at least a moderate level of management as determined by up-to-date research in equivalent environments. This means that fertilizers, lime, and green manures will be used in accordance with the needs of the crop, and that erosion and competition from weeds will be controlled.
2. The ratings are based on current levels of agricultural technology. Advances in technology may require a reevaluation of the rating.
3. The list of crops considered in this section are those which are widely grown or have been considered for commercial production. Absence of a crop from the list should not be interpreted as indicating that the crop cannot be grown.
4. The skill and resources of individual operators who can put in a higher level of management are not taken into account in the rating. Under extreme levels of management, applied with unusual skill, satisfactory yields of crops can sometimes be obtained on highly unfavourable soils. The ratings do not reflect such extreme levels of management.
5. The ratings are based on subjective rather than actual yield information, and should be interpreted in relation to this.

[b]Definitions of the individual suitability ratings are as follows:

(W) *Well Suited*

Soil capability performance groups having few or no limitations for the production of the named crop. Such areas have soils that have favourable physical conditions or ones which respond well to management, and they have terrain which is favourable for the cultivation of the named crop. Moderate to high yields can be expected provided there are no climatic restrictions.

(S) *Suited*

Soil capability performance groups having few limitations of moderate severity to the production of the named crop. Physical soil conditions and/or terrain are only moderately favourable, but these can be overcome by moderate levels of management. Yields in relation to well suited soil-land areas are somewhat reduced for similar levels of management.

(M) *Marginally Suited*

Soil capability performance groups having several limitations of significant severity to production of the named crop. Physical soil conditions and/or terrain are only moderately favourable, and these are difficult to overcome with moderate levels of management. High management inputs are necessary to obtain satisfactory yields.

(U) *Unsuited*

Soil capability performance groups having severe limitations to production of the named crop. Satisfactory production is not feasible without the implementation of severely high levels of management.

[c]Soil performance group key:

Hazards

C—compacted layer
D—drainage
E—erosion
O—organic soil
P—firm subsoil
V—stone content

Degree of hazards

n—minor
m—moderate
s—serious
v—very serious

Parent material

1—recent alluvium
2—granite
3—arenaceous shale
4—sub-recent and older alluvium

Table 5. Summation of Crop Suitability Acreages According to Soil Capability Classes and Crop Groups

SOIL CAPABILITY CLASS I—119,380 ACRES

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	104,510	102,720	—	114,620	103,720	110,050	102,510
S	14,870	16,660	—	2,970	15,660	6,540	23,400

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	111,050	112,840	46,790	52,390	28,230	114,620	—
S	8,330	6,540	72,580	52,120	65,460	2,970	—

SOIL CAPABILITY CLASS II—161,360 ACRES

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	111,050	21,420	42,080	6,350	105,650	38,670	92,940
S	9,230	90,080	—	23,350	14,620	44,530	15,930

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	23,390	78,216	4,940	74,760	—	27,260	26,950
S	52,690	26,780	106,780	19,810	16,000	55,940	15,130

SOIL CAPABILITY CLASS III—118,660 ACRES

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	13,370	—	—	—	13,370	8,900	—
S	48,200	13,370	20,440	—	28,680	50,130	13,370

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	—	—	—	—	—	—	—
S	5,230	13,370	13,370	4,763	20,438	—	20,440

SOIL CAPABILITY CLASS IV—41,200 ACRES

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	—	—	360	—	—	—	—
S	15,730	—	—	—	11,411	—	—

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	—	—	—	—	—	—	—
S	—	—	11,411	—	—	—	360

SOIL CAPABILITY CLASS V—119,550 ACRES

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	—	—	—	—	—	—	—
S	—	—	—	—	—	—	—

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	—	—	—	—	—	—	—
S	—	—	—	—	—	—	—

Special Considerations in Evaluating SRI Information for Paddy Lands

R. L. Tinsley

During the course of the workshop it became apparent that normal SRI evaluations were not always appropriate when evaluating lands currently used for or to be developed for paddy rice or other flooded crops. Since several participants were associated with SRI programs where paddy was an important component of their efforts, a special voluntary discussion session was convened to allow those interested a chance to review how SRI information could be applied to paddy lands or what modifications were needed to evaluate paddy lands, what criteria were less important, and what criteria had to be reinterpreted.

This summary has been prepared from this extra session. Since it was an extra session for which the participants did not have an opportunity for careful preparation, or a ready supply of reference material, the ideas expressed should be evaluated as a stimulating beginning high-lighting problems and concerns, and not a final end product. The discussion was focused not on delineating the criteria needed to evaluate paddy lands but on contrasting the evaluation of paddy lands to the more common SRI evaluations which emphasize upland problems.

For the sake of orderly discussion seven questions were drafted as follows:

1. What land qualities need to be emphasized or de-emphasized in working with paddy lands?
2. What physical properties of the soil need to be emphasized or de-emphasized in working with paddy lands?
3. How should the different hydrological conditions, both natural and supplemental, be accounted for?
4. What chemical properties of the soil need to be emphasized or de-emphasized?
5. What operation problems must be considered in surveying rice lands?
6. What changes in diagnostic criteria would make *Soil Taxonomy* better suited for dealing with paddy?
7. What special methodologies are needed for presenting SRI information on paddy lands to planners and decision makers?

The above questions were distributed and recollected with the participants' comments. This summary was prepared from written remarks returned with the discussion questions and recollection of the oral comments made during the discussion. This review will treat each question in order.

LAND QUALITIES

Slope

Paddy lands tend to be more sensitive to slope demarkations, largely because of the terracing and leveling of each individual paddy. The slope controls the volume of soil material that needs to be moved and thus the size of individual paddies. The size of plots can influence the possibilities for mechanization, an extreme example being the very steep terraced mountain sides which must be worked exclusively by hand. Most good paddy lands have an overall slope of 1% or less. Paddies rarely are found on slopes exceeding about 8%. The mountain terrace systems represent a dramatic exception that really cover only a very small percentage of the world's total paddy lands.

Break in slope and contour

In terraced areas the concave vs convex slopes distinguish different degrees of moisture enrichment or depletion. Frequently the concave slopes will have artesian upwellings which cause an adverse elemental imbalance and de-compaction problems. Changes from convex to concave contour will also affect moisture enrichment or depletion, but not severely enough to induce nutrient disorders. The convex contours tend to have less available natural or local irrigation water making them more suited to upland rice cropping patterns instead of double rice.

Erosion

Generally erosion does not become an important consideration even in more sloping lands. The individual paddies act as sediment traps to retain the soil until it has settled out. Also, when there is ponded water[1], this will insulate the soil from direct impact or raindrops. However, there could easily be selective erosion of the fine particles. The fines come into suspension during dispersion and move to progressively lower paddies during international drainage. The lack of erosion in paddy areas may be illustrated by the frequent lack of levees on small streams, the catchments of which are entirely composed of paddy lands. An exception to the general diminished emphasis on erosion is the terraced mountains, when a breeched paddy can trigger chainbreeching all down the mountain side in a single massive erosion incident.

Drainage

The normal evaluation that poor drainage is detrimental to crops needs to be revised. Poor drainage is normally advantageous for paddies provided there remains a net downward movement of water. Upward water movement as occurs with artesian conditions can be detrimental to paddies. It is also better to have some control in the surface water movement, particularly during the early stages of growth.

PHYSICAL PROPERTIES

Hydromorphic qualities

The general physical hydromorphic qualities of the soil become advantageous for paddy lands, when they would be detrimental to other land uses. Generally the higher degree of hydromorphism, the better suited for paddy.

[1]In this summary "ponded" water refers to water held within the bunds of the paddy and thus at least partially controlled. Flooding refers to water that exceeds the level of the bunds and thus cannot be controlled.

Texture and permeability

Generally texture needs to be emphasized with the more clayey and less permeable soils being more beneficial than the sandy coarse-textured soils, unless the latter are located with a high watertable.

Water table

The depth of the water table becomes more important in paddy lands. The suction gradient between the true water table and the ponded surface water will affect the deep percolation of water and thus the rate of water loss through the soil profile. A water table close to the land surface is preferable to a deep water table a meter or more beneath the surface. However, artesian upwelling can be detrimental.

Compactability

Because the saturated surface condition cannot support movement, the soil immediately below must be sufficiently compacted to support all traffic on the paddy. This compaction could be the natural consolidation of the soil or the formation of an artificial traffic pan. The traffic pan would be a narrow horizon in which the soil was more compacted than the naturally compacted soil below it. This extra compaction may also contribute to reducing infiltration and deep percolation. Evaluating the problem may require a complete review of current parameters with possible development of additional parameters. Areas with upwelling water may require additional study in both classification and corrective methods. The upward water flow may tend to encourage a progressive decompaction of soil through the entire profile, even after the lower horizons have been completely consolidated during an abnormally dry period.

Aggregate dispersion

Instead of evaluating aggregate stability, a measure of aggregate dispersion may be preferred. The wet cultivation attempts to disperse as much of the aggregates as possible in order to seal the soil and reduce deep percolation. Thus soils that disperse easily would have an advantage in paddy use. For intensive land use involving both paddy and upland crops an additional measure of re-aggregation may be desired. Techniques required for accurately and appropriately evaluating dispersion/re-aggregation problems of paddy lands may need to be developed.

Conversion potential

When upland crops are grown in sequence with rice, the conversion from paddy use to upland use might require not only re-aggregation, but also considerable soil manipulation. This would involve rapidly forming the beds and drainage canals now needed to protect against excessive water. Even though the average climate may become dryer during the non-paddy period the land usually must be protected from even a single sudden high-intensity precipitation incident. Some measure may be needed to evaluate ease of soil manipulation.

Soil depth

Under fully irrigated level land conditions the depth of the soil below the plow layer is considerably less important than in non-paddy use. Not only does the traffic pan provide a physical barrier for root penetration but also the ponded water provides

adequate moisture, and increases availability of nutrients, so roots rarely need to penetrate below the top layer. Under rainfed paddy conditions soil depth can again become important but still less so than under upland conditions. However, when sloping land is going to be graded for paddy use requiring substantial amounts of soil movement, the soil depth becomes extremely important in the initial field layout and individual paddy construction.

HYDROLOGICAL CONDITIONS

Natural

Perhaps the most distinctive feature of paddy lands is the intentional retaining of water on the soil surface. This leads to a complete additional vector of land evaluation features that can be critical to paddy, but rightfully discarded in upland, evaluations. Unfortunately the hydrologic vector is "fluid" and can result in rapid changes in land qualities in both time and space. Without irrigation to stabilize the deficient side, the hydrologic values will vary grossly between wet and dry seasons of the year, then vary broadly with variation in rainfall between years (CV for wet months rainfall commonly approaches 50%) and finally vary narrowly with variation in incident rainfall between surges and lulls in storm frequencies. Once on the ground the water continues to flow over and through the landscape providing localized areas varying in moisture enrichment and depletion. The degree of these changes frequently is a function of the previously discussed variables in water supply, as well as intentionally manipulated intrapaddy overflow. Substantial changes in land qualities often occur within only a few cms difference in elevation. This provides a tremendous degree of highly mobile variation in land qualities that requires an evaluation of the overall dynamics of soil, land, and water interaction that may be difficult with more normal SRI methodology.

Within this dynamic framework several hydrological conditions can be identified that will account for a substantial amount of water movement across the land surface (overflow) and through the soil profile (interflow). These are:

Depleted. Areas with a net loss of water to surrounding area. Frequently these will be minor rises in the general landscape that can marginally be used for paddy and are often used as isolated upland cropping areas, surrounded by paddy.

Neutral. Areas of nearly level slope (1% or less) for which overflow either into or out of the paddies is slow and generally balanced. A subsurface water table occurs well below the ponded paddy water with an unsaturated horizon in between. This puts the ponded water under substantial moisture tension, increasing the rate of deep percolation.

Overflow enriched. Areas with a little more slope (from 1 to 8%) that allows rapid overflow enrichment from upper paddies to lower ones. The lowest paddies may also receive some interflow.

Groundwater enriched. Areas that generally have a shallow water table directly connected to the ponded surface water. This reduces deep percolation. Generally these areas are flat, similar to the neutral areas, so there is little potential for overflow enrichment.

Seepage enriched. These are generally small areas in which seepage water comes in from the sides, but not from the bottom. This is usually advantageous to the rice and

prolongs the growing season. Frequently these areas will be minor depressions such as old streambeds. They occasionally become flooded over the bunds and thus may require tall varieties during mid-rainy season.

Upwelling enriched. Areas, generally quite local in extent with an artesian water flow coming up through the bottom of the soil. These areas are generally found on the bottom of steep valleys without incised streams, or in terraced areas where the slope changes from convex to concave.

Moderately flooded. Areas in which uncontrolled flooding regularly occurs to a sufficient height to restrict the use of short-statured rice varieties. The flood height would normally peak at between 40–100 cm and require tall erect varieties with some elongation potential but not the floating varieties.

Deeply flooded. Areas in which uncontrolled flooding regularly occurs to a sufficient height to require floating prostrate varieties. Water height would exceed 1 meter and could reach 5 meters.

Irrigation

To an increasing extent paddy lands receive some form of supplemental irrigation water. This can vary from very local seepage collection/re-distribution schemes, to non-storage stream diversions, to major projects involving large-scale storage and covering 500,000 to 1,000,000 ha. The vast majority of the paddy irrigation schemes are gravity-operated flooding systems. Rarely are pumps utilized except on small individual farm systems. The need for extra water to satisfy soil percolation demands make large pumping schemes economically questionable. The availability of irrigation constitutes major changes in land quality for paddies. This really needs to be an integral part of SRI studies, perhaps to a greater degree than when irrigating non-paddy areas. Because most paddy irrigation schemes are relatively new the effect of the extra irrigation water on diagnostic soil criteria may not have materialized. Fortunately much of the gross influence on land values can readily be interpreted from the design and operation of the specific irrigation scheme and basic land qualities. Again because of the desire for retaining surface water there are a couple special considerations that may need emphasis. They are:

Distance from source. In most large schemes there is an appreciable decrease both in volume and dependability of water as distance from the source increases. This is the result of hoarding in the upper portions of the scheme to the detriment of lower portions. Pond water allows each individual paddy to become a mini-reservoir, reinforcing this hoarding tendency and making it a more serious problem in paddy irrigation schemes than in corresponding upland irrigation systems. In upland systems the excess water would rapidly be detrimental to crops. This hoarding problem appears largely a managerial one, but an extremely complex and sensitive one. Most major paddy irrigation schemes in Asia involve small farms for which it is virtually impossible to accurately administrate a volume control on water to each farm. Without a volume control farmers are not motivated to minimize use and tend to hoard as much as possible (without regard for colleagues down the scheme whom they rarely meet). Land quality surveyors really need to put a function of this in their evaluation, and engineers need to consider designs that will assist in more equitable distributions.

Landscape inversions. When irrigation canals are placed along the top of the scheme so that water flows across the contours, the natural moisture enrichment as a function

of relative position on a slope with the bottom land the most enriched will be reversed. Proximity to the canal will become more important, making the highest lands the most enriched and advantageous for paddy.

Induced upwelling. When irrigation schemes are put on more permeable soils and considerable water has to be applied to retain a ponded surface, the reappearance of the surplus water in lower parts of the catchment can occur as localized adverse upwellings. This can affect as much as ⅓ of the lower catchment of some schemes, and may have to be accommodated in post-scheme inventories of area. These upwellings would be difficult to accurately predict in scheme development-oriented SRI.

CHEMICAL PROPERTIES

Chemically evaluating soils for paddy use generally would require accounting for problems of reduction and dilutions of soil solution. This changes the emphasis of some regular chemical properties and may require additional criteria specific for paddy. Some of these are:

Oxidation/reduction

A fundamental difference in chemical activity between paddy and upland soils is the reduction chemistry that occurs in paddy soils. This controls the availability of many ions and compounds which are either essential to the rice or toxic to it, the most important of which are the ions of P, Fe, and Zn and the toxin H_2S. The amount of reduction in a soil is controlled by duration of inundation, the amount of readily available organic matter that serves as a substrate for the reducing microbes, and the amount of reducible material. The extent of reduction in most soils is generally buffered prior to formation of serious toxin by reducible inorganic compounds such as Fe_2O_3 and MnO_2. This could be partially analogous to the way CEC buffers acidity in upland soils. Thus for good paddy land evaluation it might be desirable to develop a characterization measure of the reduction potential of a soil.

Soil reaction

Under reducing conditions soil pH tends to move from either extreme towards neutrality in most, but not all, soil. Thus paddy lands do not need accurate pH analysis in the mid-pH range for soil, i.e. from 4.5 to 8.0. Outside of this range well-defined adversities occur and more careful consideration of pH would be necessary. Normally corrective measures such as liming for acidity are not required for rice and need not be part of paddy evaluations. Special consideration must be given to acid-sulfate soils when they are developed for rice.

Salinity

Salinity becomes important largely because rice is one of the best remedial crops on saline lands. If the water is available, the ponding will dilute the salts to a tolerable level or physically depress the salt accumulation to lower soil horizons and if continued long enough provide for permanent corrective leaching that will force the salts out of the system, while at the same time productively utilizing the land. There are now several good salt-tolerant rice varieties available.

Organic matter

The importance of organic matter may require some refocusing. The organic matter is required as a substrata for reducing microbes. However, this would generally be the fresh organic matter, the content of which rapidly changes with season and cannot be a criteria for characterization analysis. The second role is as a clod cement that reduces the tendency of the super-saturated puddled horizon to crack upon drying. This would most likely be attributed to the more stable forms of organic matter, than can be a part of characterization analysis.

Fertility

As mentioned previously the oxidation/reduction chemistry of paddy soils affects the availability of many nutrient elements. This forces a reevaluation of both the indexes used to characterize fertility status and the levels obtained with fertility indexes. In most cases P and K become more available under paddy conditions, so their index level can be revised downward. However, Zn will become less available so its index needs more critical attention, depending on pH and inundation duration. Fe can be either toxic or deficient depending on reaction and hydrology, and needs critical attention on both ends.

Organic soils

Organic soils would initially appear to be ideal for paddy rice because of the basic wet environment and adverse effect on the soil when drained due to dissolution and oxidation. However, organic soils have always presented a multitude of difficulties when used for paddy. Much of this appears related to the availability of various micronutrients such as Cu, Fe, Mo, etc. Also undrained organic soils have very limited compaction that severely hinders their physical management.

SURVEYING

The actual field investigation of paddy lands provides several unique considerations not generally encountered in upland surveys. These considerations can either hinder or assist the investigations. These include:

Time of survey

Because the ponding of water and subsequent reduction will cause a temporary change in soil color, it is essential for accurate evaluation that sampling be done on either completely oxidized or completely reduced conditions. However, the oxidized condition is greatly preferred because it avoids the temporary gleying and is thus a more stable value. Unfortunately it frequently is not possible to have the entire area oxidized at once except during the middle of the dry season when much of the area will be too dry for easy augering. More often than not the higher part of the surveyed area will be dry while the lower ponded. This would necessitate multiple sampling dates.

Importance of color

Hydromorphism is generally accurately conveyed by soil color. Thus when evaluating paddy lands the surveyor needs to concentrate extensively on relatively fine distinctions in soil color, much of which may require refinement in present techniques.

Frequently differences in land qualities can be determined by relative changes in gray colors from various portions of a paddy. However, the absolute values may not extrapolate to other areas where parent material differences have caused basic differences in color matrix. This needs some more extensive study.

Terracing

The physical construction of paddies, involving leveling of each indicated paddy, can cause an appreciable difference in soil depth between the front and back edge of the paddy. This can be a serious problem in more sloping areas and lead to major differences in crop performance within a paddy. Also it leads to a technicality as to how to sample the paddy.

Flood depth

In areas in which the flood water routinely exceeds the paddy bunds, there is a need to estimate the level of flooding. This is not generally reflected in pedological characteristics but can generally be obtained from interviews with residents and farmers.

Paddy mosaic

The pattern that individual paddies form on the ground, and changes in that pattern, are frequently a good indication of changes in land qualities. In more level areas the paddies tend to be large and square while in more sloping areas they tend to be narrow, irregular, fitting into the contour. The shift from one configuration to another can frequently be used in delineating changes in land elements. The paddy mosaic generally shows up clearly on aerial photographs, allowing for considerable accuracy in making delineations.

General discomfort

The wet muddy condition of paddies makes for a certain general discomfort in work, frequently requiring barefooted operations, that subject the worker to various health hazards not associated with upland activity.

SOIL TAXONOMY

Accurately evaluating paddy lands will eventually lead to several improvements in the taxonomic criteria used to classify soils. This would mostly concentrate in more sensitive subdivisions of the hydromorphic or aquic qualities. Some of these would include:

Anthraquic horizons

This is a horizon described by Frank Moormann, in which a surface gleying or pseudo-gley is found above an ungleyed horizon. This is due to inducing hydromorphic conditions in better drained soils making the surface more reduced than the area below. This generally is a direct result of bunding and puddling the soil to encourage ponding of water in areas that if unaltered by man would not retain free water.

Flooding regime

There will probably be a need to define various flooding regimes as part of different aquic suborders. These would designate different rice variety group limitations and might include:

less than 30 cm—suitable for short varieties
30 to 100 cm—require tall or elongating erect varieties
greater than 100 cm—require floating varieties.

Fe/Mn accumulations

After prolonged use for paddy some soils develop a Fe/Mn accumulation horizon just below the traffic pan. When it occurs this is a readily identifiable diagnostic horizon, and a reasonable indicator of the length of time the land has been used for paddy.

PRESENTATION

The discussion session had to be adjourned prior to really discussing the last question. However, it was recognized that frequently the variability in paddy lands exceeded the details that normally could be mapped. In such case an alternative means of presentation may have to be developed to account for regular grouping of various distinct paddy land elements in one mapping unit.

CLOSING

This concludes the discussion on paddy lands. Again this summary is not intended as an all-inclusive description of the problem associated with SRI work involving paddy lands, but only those ideas presented at the extra discussion session. It is hoped that this will provide a stimulus for further thought and study by any individual requiring to adopt SRI investigations to paddy lands.

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LITERATURE CITED

Kawaguchi, K., and K. Kyuma. Paddy soils in Tropical Asia. University Press of Hawaii, Honolulu, HI.

Moorman, F. R., and N. Van Breemen. 1979. Rice: soil, water, land. International Rice Research Institute, Los Baños, Philippines.

Interpretations of Soil Surveys for Agricultural Purposes in Colombia

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Soil surveys have been carried out in Colombia for about 25 years under the responsibility of the Instituto Geográfico de Colombia "Augustín Codazzi." In general, the methodology followed that proposed by the Soil Conservation Service (U.S. D. A., 1965), but was modified according to the nature of the country and selected criteria.

There appear to be some gaps in gathering the information and giving recommendations for regional planning or for specific farms. Apparently, agronomists and farmers are unable to find the information they need and/or apply the practical recommendations to particular situations. Therefore, the present paper intends to show briefly how the soil survey is made and used for agricultural purposes and to point out some of the problems which should be considered in order to make the soil survey more useful for land utilization purposes. The paper includes information on the procedures of data collection and the way the data are used to make recommendations. A general evaluation on the application and usefulness of soil surveys for land use and soil management purposes is also presented.

THE SOIL SURVEY

Depending upon the importance of the area and the purposes of the study, the field work is performed with little or much detail (Mosquera, 1972). For the sake of brevity and for the purpose of the paper, we will only consider the "detailed" soil survey for more developed, flat areas (roughly equivalent to the 2nd order), and the "general" for undulating and non-developed areas (roughly equivalent to 4th order).

Mapping units

In detailed soil surveys, soil consociations, soil series, and soil complexes are used and in general soil surveys, soil associations.

Kinds of components

Detailed soil survey maps show phases and types of the soil series (slope, erosion, effective depth, salinity, etc.). In general surveys, soil "families" (but not in its present sense of *Soil Taxonomy*) have been employed.

Soil cartography

In detailed soil surveys, scale is an average of 1:10,000 or less, with little or no photo-interpretation support. The mapping units include about 15% inclusions of other taxonomic units.

In general soil surveys, scale of the maps ranges from 1:60,000 to 250,000, with considerable photo-interpretation support. Soil units are delineated as associations of the predominant soil series.

Soil correlation

The correlation work is done by a team of soil scientists; it includes both local and national correlation. The local correlation is performed at the end of the field work in order to make inspections and observations of the soil profiles, to check some mapping units, and to establish definite taxonomic units, descriptions of the soil units, and their range, legend, and final cartography. The subgroup is also indicated.

The national correlation is done after the soil samples are analyzed and during the preparation of the soil survey report. Discussions on the soil descriptions plus laboratory data will show how the soils of the area correlate with other ones of the same or different areas. The final draft of the soil map is adjusted, definitive legends are checked, soil classification following *Soil Taxonomy* at levels higher than soil series is proposed, and a final soil map is elaborated.

For detailed soil surveys, a map showing different classes of land for irrigation purposes is prepared. In general and detailed soil surveys, a land capability map (U.S.D.A. system with modifications) is prepared, retaining the original boundaries of the mapping units.

The soil survey report

The report includes some general characteristics of the area (geology, geomorphology, climate, vegetation, land uses, etc.); descriptions of the soil profiles (two or more of the same soil series in detailed surveys); the general description of the soils series and their ranges of variation, phases, and legends; laboratory analysis of the profiles described (two or more for detailed soil surveys); and interpretation of the soil analysis. Lately, chapters on soil genesis, taxonomy of the soils at higher categories, and recommendations on land use and soil management have been included.

USE OF SOIL PROPERTIES FOR RECOMMENDATIONS ON LAND USE AND SOIL MANAGEMENT

On the basis of the information on soil properties provided by field and laboratory studies, detailed soil surveys include a special chapter dealing with land use and soil management. This material is prepared by a team of soil scientists with training in different disciplines (such as soil chemistry, soil fertility, soil physics, soil conservation, beef cattle, dairy, crop production, ecology and soil taxonomy, and of course, soil survey). The report also includes information or data obtained by other agencies on these subjects. It follows the purposes, scope, procedures, and recommendations outlined below.

Objectives

To evaluate the general conditions of the area and the soil properties in order to give proper recommendations on the best use and management of the land, both for better soil conservation and maximum crop yields under various levels of inputs.

Scope

The appraisals and recommendations of the report are focused toward governmental agencies, agricultural enterprises, and small farmers, either for regional planning or for individual farms.

Procedures to make evaluations of soil properties and recommendations

The evaluation of soil properties to make specific recommendations on land use takes into consideration:

1. The external or general conditions of the area, such as: infra-structure, marketing, economics, tradition, water sources, and some soil properties like relief and micro-relief, soil moisture regimes, and soil temperature regimes. This type of pre-evaluation will suggest the general suitability of the area for specific land use, e.g. annual crops, plantations, fruit trees, beef cattle, dairy, forestry, or irrigation districts.
2. The internal soil conditions, such as morphological, physical, chemical, mineralogical, and biological soil properties. Evaluation and/or information from other agencies on these subjects will suggest the particular conditions of the soil, workability and tillage, plant variety, root growth, nutrient status, amounts, methods and frequency of fertilizer application, liming and micronutrient problems, rotation of crops, weed control, etc.

The Colombian Agricultural Institute (I. C. A.) has had as its responsibility for almost 25 years research on agriculture for the whole country. This investigation has been carried out at 17 experimental stations located at rather representative places in the Andean valleys, the coastal plains, and the highlands of the cordilleras of the western and more developed parts of the country, and to a lesser extent in the low non-developed tropical areas. Soil scientists have conducted research on soil physics, chemistry, fertility, classification, microbiology, irrigation, and drainage and management practices, both at the stations and in regional trials with the farmers. Experimental stations have detailed or ultradetailed soil surveys (1st or 2nd order); trials outside of the stations have been located on representative soil series of the area. Results obtained at both areas have been statistically analyzed and correlated in order to establish the soil response to the treatments under different conditions. Likewise, these studies have been supported by the information brought by specialists from other disciplines. Most of ICA's investigations on soils have been oriented toward levels, sources, and frequency of fertilizer application for the main crops of the country and also toward laboratory and greenhouse studies on calibration of the methods of soil test analyses. Results have suggested specific recommendations on N, P, K, lime, and micronutrient application on different crops in several areas. Other soil studies have been conducted on tillage, irrigation, drainage, salification, manure, green crops, plant population, and economics of fertilization. Many results obtained have been published and are currently used by people of the National Soil Survey Program (Cortés, 1976), farmers, other agencies, and agronomists assessing crop production.

INTERPRETATION AND EVALUATION OF SOIL CHARACTERISTICS

The following are some examples showing the criteria and the applications of selected soil properties for land use and soil management in Colombia. (These are only simplifications and/or generalizations, not for specific situations. Considerations are restricted to some outstanding points.) Table 1 summarizes the information presented in this section.

Appraisal of some morphological characteristics

Mottling. For many soils, low chroma mottles are associated with excess of water, restriction of internal drainage, and limitations for root growth.

For other soils, restricted drainage influences, but does not necessarily exclude some crops. Therefore, mottled soils could be selectively used for some crops while for others a drainage system must be foreseen.

Effective depth. Root growth, internal drainage and, eventually, tillage may be limited by factors affecting the effective depth. Crops with a less-developed root system could be suitable for soils of this nature.

B-cementation. The presence of a cemented or indurated layer in the B horizon near the surface limits the natural drainage and the root growth and favors low infiltration rates. Conditions of this nature may be an advantage for irrigation purposes but a disadvantage for dry-land crops.

Appraisal of some physical properties

Coarse textured soils. Generally, fertility is lower and, depending upon the moisture regime, irrigation is required. As a consequence, coarse textures affect the water management and the soil productivity.

Medium textures over fine textures. The presence of medium textures over fine textures in flat areas decreases the infiltration rate and favors water retention. This could determine the suitability of the land for rice under irrigation.

Very high clay content. For soils having 2:1 clays, this indicates tillage problems and drainage limitations. Consequently, depending upon the amount and distribution of rainfall and the economics, one should consider a drainage system, or alter the date of soil preparation and/or land use.

Appraisal of some chemical characteristics

Organic matter content. Usually N-response is well correlated with organic matter content. Depending on the crop, the altitude, and nature of the organic matter, there will be N-responses if the organic matter content is low, especially on graminae.

Phosphorus problems. For many soils, the P deficiencies seriously limit crop production and are closely associated with high acidity. In such a case, a P-fertilization program is required. In Colombia, ICA has found some reasonable recommendations on P fertilization, mainly as basic slag (Escorias Thomas). For most soils, P problems also require a liming program. Therefore, if P is deficient, land use and economics of soil management must be considered.

Salinity-sodicity problems. The presence of saline and sodium compounds causes limited productivity of the land and restricts the range of crops. Land utilization and soil management must consider tolerant crops, soil reclamation practices, and regional drainage systems.

Table 1. Selected examples of the use of soil properties in making recommendations on land use and soil management (simplification).

Soil Property	Condition Affected	Implication
Morphological		
Mottling	Internal drainage, water content, aeration	Drainage practices or selected crops
Effective depth	Root growth, drainage	Type of crop, limited use
B-cementation	Root growth, drainage	Type of crop, drainage
Physical		
Coarse textured soils	Fertility, water management	Productivity, irrigation
Medium textures o/fine	Water content and management	Selection of crop, suitab. for rice
High clay content	Tillage, drainage	Physical problems, conserv. practices
High water infiltration	Content and retention of water	Type of crops, frequency of irrigation
Chemical		
Organic matter content	Nitrogen content	N-responses, management of org. matter
Available phosphorus	Fertility, plant growth	P-fertilization, crop selection, economics
Salinity/sodicity	Plant growth, yields	Land reclamation, select. crops, economics
Mineralogical		
Dominance 1:1 clays	Tillage, drainage, fertility	Fertilization, select. crop, planning
Dominance 2:1 clays	CEC, fertility, physical conditions	Tillage, drainage, productivity
Dominance of allophane	Availability of P, fertility	Select. of crops, fertilization, economics
Climatic		
Soil moisture regimes	Plant growth, weed control, soil mgmt.	Selection of crops, potential, planning
Soil temp. regime	Plant growth, type of crop	Select. of crop, limited use, planning

Appraisal of some mineralogical properties

Dominance of 1:1 clays. Most of the soils in which 1:1 clays are predominant have low fertility status but good physical conditions. This favors tillage but affects fertility and potential productivity for specific crops or regional planning.

Dominance of 2:1 clays. Opposite to the 1:1 situation, soils in which 2:1 clays are dominant generally have a high fertility but represent poor tillage conditions. Use of these lands and soil management practices must include considerations on the use of machinery, drainage, and productivity.

Dominance of allophane. It has been observed that P-fixation is significantly higher in soils in which allophane content is high. Since Andosols are quite common in Colombia, the use of these lands and soil management practices considers heavy P fertilization, light N applications, and some liming. Small farmers are getting reasonable yields utilizing their plots with intermixed crops.

Appraisal of climatic characteristics

Soil moisture regimes. Deficiencies or excesses of moisture content in the soils produce strong limitations on the yields of most crops. Plant growth and soil management are closely related to the amount and distribution of the rainfall. Therefore, land use and soil management consider soil moisture regime when recommending particular crops or pastures for a given area.

Soil temperature regimes. The same type of considerations exist for temperature regimes. The presence of frost and temperatures below freezing at high altitudes, mainly during the dry season, are quite important for plant growth, especially for broad leaf crops.

In summary, the chapter on land use and soil management of the soil survey report presents: in detailed surveys, special recommendations on suitability for land use (annual crops, livestock, irrigation districts, etc.) and soil management and cultural practices (drainage, irrigation, liming, tillage, fertilizers, weed control, etc.). The general soil survey report includes a general pre-evaluation of the lands for broad state-wide and regional preliminary plans, colonization projects, beef cattle, etc. It also includes some general remarks on suitability for crops, nutrient status, physical problems, and fertilizer needs.

EVALUATION OF THE COLOMBIAN SOIL SURVEY AND RECOMMENDATIONS

In general, it appears that the Colombian soil survey is presenting reliable and practical information for specific areas of the country, in regard to suitability of the lands for different purposes (crops, livestock, forestry, etc.), according to the general conditions of each area; the nature of the soils; and their physical, chemical, and climatic characteristics. The survey emphasizes their advantages and serious limitations for specific uses, land capability, and suitability for particular crops and mentions some necessary management practices. At present, directors of the program are introducing some changes in the field work, report, and cartography in order to improve the quality and usefulness of the work for potential and actual users.

However, there seem to be particular situations which are limiting the usefulness of the studies. Some of these are mentioned in the following paragraphs.

Logistic limitations

1. Insufficient up-to-date air photos and related cartographic material.
2. Insufficient budget, personnel, and facilities.
3. Delay in the publications: writing of the manuscripts, editing the report, and publishing colored maps.
4. Insufficient soil correlation at the local and/or national level.

Evaluation of the recommendations

Most of the recommendations on land use and soil management are done for large areas shown on the maps, but the user is looking for specific recommendations for individual farms. In the future, Colombian soil survey could consider the following aspects:

Inclusions. Since inclusions are not presented in the soil map, there may be some errors generated by applying the same recommendations to the inclusions as to the soil series, especially in small farms in which the mappable size areas are out of the scale.

Soil "families." Until a few years ago, soil families as presented in the soil map were within the old, obsolete concept of this category (that is, by grouping soil series having rather similar characteristics). The recommendations presented for such soil series should be revised.

Fertility recommendations. The interpretation of the soil analysis and subsequent recommendations on application of fertilizers for the soil series, on basis of the samples taken at one or two pedons, may lead to wrong conclusions. As a matter of fact, the range of variation of the soil fertility of the surface layer of a particular soil phase may show great differences from place to place in the same area and even within the same farm, depending upon the land use and soil management in the past, and to some extent on natural variation in the range of the original properties.

Another point in relation to fertility appraisal of specific land units is that the original recommendations were made on a particular date and at the present time they are not up-to-date. However, they become of rather permanent character, not taking into account early and late uses and management practices of the different plots in the field. Actually, recommendations for fertilizer applications by ICA were obtained on particular soil series and some have been generalized for the whole area or farms.

Land capability classes. The map of land capability classes (adapted from the U.S.D.A. system) represents to some extent qualitative rather than quantitative appraisals. Therefore, decisions on specific situations become highly subjective and subject to different evaluation from person to person.

Map scale. In areas on which small farms are predominant, the scales of the maps do not permit exact identification of individual farms for specific recommendations.

"Overlapping" of the orders of soil surveys. In some cases, the information given in "detailed" (2nd order ?) soil surveys is rather generalized, and vice versa; data contained in "reconnaissance" soil surveys is rather specific.

"Ceiling" of recommendations. The recommendations on land use and soil management should not have more specificity or scope than that given by the "type" or order of the soil survey.

LITERATURE CITED

Cortés L., Abdon. 1976. Los Suelos de Colombia y su Aptitud de Uso. (In Spanish). Dirección Agrólogica, Instituto Geográfico de Colombia "Agustín Codazzi." Bogotá, Colombia.

MOSQUERA L., LIBARDO. 1972. Normas para descripción de Perfiles y Unidades Cartográficas de Suelos. (In Spanish). Dirección Agrólogica, Instituto Geográfico de Colombia "Augustín Codazzi." Bogotá, Colombia.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). 1965. Manual de levantamiento de suelo. (In Spanish. Traduction "Soil Survey Manual, U.S.D.A., Handbook no. 18," por el Ing. Agr. Juan B. Castillo.) Ministerio de Agricultura y Cia, Sección de Conservación de Suelos. Venezuela, Caracas.

PART ONE

SOIL RESOURCE INVENTORIES

Section V

Kinds of Soil Survey Interpretations

Comments on Interpretation Potentials in Relation to Soil Survey Orders

Arnold C. Orvedal

The value of soil surveys as resource inventories depends on what interpretations can be made from the soil maps and supporting documents.

In my discussion I shall refer to the recent classification of orders (classes) of soil surveys developed by the U. S. National Cooperative Soil Survey (Chapter 2 of the new draft of the *Soil Survey Manual*, revision dated 4-75). These orders, of which there are five, are unavoidably broad and each order encompasses a rather wide range in kinds and intensities of surveys. Yet, this classification is the best we have, at least in the United States. It is a big improvement over what we have had before.

ORDER 1

It is rather obvious that the greatest number of potential interpretations and the highest reliability of interpretations reside with soil surveys of order 1. This is the order with the largest map scales and therefore is potentially the most precise geographically. In this order, the soils are classified according to phases of series — the most precise classes in the U. S. soil survey system.

Of all the categories in the U. S. *Soil Taxonomy*, (U. S. D. A., SCS, 1975) the soil series names connote the most information and have the narrowest ranges in soil properties. Nevertheless, at the level of soil survey order 1, most soil series permit ranges too wide in some characteristics for the objectives for which order 1 soil surveys are made. To overcome this short-coming, liberal use is made of soil phasing — subdividing the soil series for purely pragmatic purposes—so as to attain the specificity needed to meet the objectives.

In the United States, not many soil surveys qualify as order 1; most of them are order 2. Order 1 soil surveys are made for purposes that require appraisal of soil resources as small as experimental plots and building sites.

ORDER 2

Soil surveys of order 2 portray the soil geography on maps with scales between 1:12,000 and 1:31,680. In the United States the most common map scale today is

1:20,000 (3.17 inches to the mile) with 1:15,840 (4 inches to the mile) ranking second. In the spectrum of soil map scales from the largest to the smallest, these scales are considered large. They permit areas as small as 1.0 to 1.6 hectares to be shown on maps. They permit more than one kind of soil to be shown on most farmers' fields. The scales are large enough to permit reorganization of field layouts on most farms so as to adjust soil use and management to kinds of soils.

Let us look at the soil survey of Lexington County, South Carolina (Lawrence et al., 1976), a modern survey of order 2. The soil map is at the scale of 1:20,000. Most of the soil map units are consociations of phases of soil series. Most of the phases are texture and slope phases, indicating that the soil series names connote the other information needed for the objectives of this survey. This survey shows three consociations of the Cecil series. All carry the texture designation of fine sandy loam; but the three consociations differ in slope, and these differences in slope are highly relevant to the use and management of Cecil soils in Lexington County.

The soil survey of this county carries ratings of the soils for 25 kinds of uses covering the principal kinds of crops grown there, an important pasture grass, elements of wildlife habitat, certain engineering uses, and land uses relevant to town and country planning. In addition, it points out key soil features relevant to seven engineering soil uses for which ratings are not given, and it also classifies every soil in the U. S. land capability classification system (Klingebiel and Montgomery, 1961). The interpretation potential, as demonstrated by the soil survey of Lexington County, obviously is high, and it provides a great deal of information about the soil resources of that county.

If the soil survey of Lexington County had been order 1 rather than order 2, how much more resource information would have been provided? There probably would have been some refinement in phase designations. The main gain, however, would have been in greater geographic precision of the delineations and greater purity of the map units. Some delineations smaller than 1 hectare may have been shown.

ORDERS 3–5

If the soil survey of Lexington County had been a 3rd order survey, how much information would have been sacrificed? There probably would have been fewer consociations and more associations. The same array of interpretive ratings probably would have been made, but some geographic precision about areas to which the interpretive ratings apply would have been sacrificed. The survey nevertheless would have had a high utilitarian value.

Let us now skip to a 5th order soil survey. In fact, this particular survey probably would be beyond the upper limit of a 5th order survey if it had an upper limit. I am referring to a soil map made by the Brazilians for the vast interior of Brazil (Ministério da Agricultura, 1966). The scale is 1:5,000,000 and hence the smallest delineation is about 100,000 hectares, which is equal to the size of some of the smaller counties in the United States. The Brazilians qualify this map as being both schematic and a first approximation to guard themselves against users putting too much confidence in it.

Nevertheless, this map is highly informative. By making liberal and skillful use of phases, the Brazilians have a map, even at this small scale, good enough to serve as a base for technical land classification maps. They have made three, all at the scale of 1:5,000,000, showing the general suitability of the soils for the production of annual

cultivated crops and perennial tree crops under assumptions of three broad management systems. One map portrays the soil suitability assuming "primitive" management, another "semi-developed, without irrigation," and the third, "developed, without irrigation."

This Brazilian experience demonstrates that soil maps at small scales can be informative and useful if the maps are well designed. Even though no more than general interpretations are possible, such interpretations nevertheless are useful in agricultural planning for large regions.

TERMINOLOGY

We have a problem with terms for expressing interpretive ratings. In the United States, we express nearly all ratings in qualitative terms: for suitabilities—good, fair, poor, and unsuited; for limitations—slight, moderate, severe, and very severe. We have found that our soil survey users find a 3-class or 4-class rating system adequate for their purposes, and they probably would look askance at a 7- or 8-class rating system.

We do not have, at least not yet, a hierarchic set of rating terms. To have such a set would be useful. For the small-scale soil maps we depend on admonishing the users of the fact that exceptions to a rating, or ratings, given for the soils within a delineation is to be expected; and we hope that users will exercise appropriate caution.

LIFE OF INTERPRETATIONS

For how long are interpretations valid? All or nearly all interpretations are ephemeral; but the length of time different interpretations remain valid varies greatly. In the United States, perhaps the first interpretation to become somewhat obsolete was the only one that is routinely expressed quantitatively, i.e., the yield estimates of wheat, corn and other crops. As new varieties are introduced and better ways of managing the soils evolve, the yields tend to increase.

Also, as new management systems evolve, some soils now considered unsuitable for cropping may become suitable. Let us look again at the soil survey of Lexington County, South Carolina. In it there is a soil suitability scale of 1 to 4 for cropping. Class 1 is the best; 4 is the poorest. Cecil fine sandy loam, 10 to 15 percent slope, is rated as 4. Under the prevailing soil management systems used today in Lexington County, this rating of 4 means that this strongly sloping phase of Cecil soil should not be used for cropping, and estimates of corn and wheat yields are not provided. If and when the no-till management system becomes common in Lexington County, will this strongly sloping Cecil soil command a better rating than 4? Probably it will.

The fact that soil survey interpretations eventually become obsolete, however, is not particularly serious for two reasons. One is that most interpretations are valid for at least several years, many of them for many years. The second reason is that if they are based on a good soil survey in the first place, old interpretations can be updated and new ones made without making a new soil survey, although some revisions in the mapping may be necessary. We might add a third reason, which is hidden in the vagueness of the rating terms. Whether a soil is rated good, fair or poor for a given use depends at least in part on judgment interpretations for which the rating criteria are as

quantitative as we can write them. If the advancement in soil management applies about equally to all soils, a soil rated as moderately suitable yesterday may still rate the same tomorrow because all the rating terms will have been upgraded and the relative position of the soil in question probably remains the same.

RELIABILITY

There are two aspects to reliability of interpretations. One pertains to the soundness of the soil map itself and the supporting documents. Obviously, geographically reliable interpretations are not possible if the map itself is inaccurate or lacks sufficient documentation.

The second aspect has to do with knowledge of the use for which an interpretation is made. In order to evaluate a soil for the production of wheat, for example, the soil scientist needs to know what the soil requirements of wheat are, and what the farming system is under which wheat is to be grown. To evaluate a soil for septic tank filter fields, the soil scientist needs to know which soil characteristics limit such use and which do not. In the United States, help from agronomists, foresters, engineers, and others has been necessary to set forth the soil criteria for the interpretations that are now made, and usually the associated scientists help soil scientists make the interpretations too.

We might mention a third aspect, and that is the degree of specificity with which an interpretation is expressed. If it is expressed in broad, non-specific terms, the reliability may be said to be high although the soil map may be less useful than it would have been if the interpretation had been expressed with greater specificity.

EFFECTIVENESS

The effectiveness of a soil survey depends on how much it is used as a source of information for making decisions about soil use and management. Several factors relate to effectiveness; I shall deal with only one.

In my experience, maps that are difficult to use simply are not used. Not only must delineations and symbols be legible, the legend must be well organized too, especially if the number of map units is large. The organization should be such that any map user can quickly and easily find in the legend the symbol in which he is interested. This usually means that the symbols should be alphabetically or numerically arranged. Anyone who has used the soil survey of Puerto Rico published in 1942 or the soil association map of the United States published in the 1938 USDA Yearbook of Agriculture will know what I'm talking about; the symbols on these maps are not arranged alphabetically. As elementary and obvious as this legend-organization rule is, I am still surprised to find many maps on which it is not followed.

CONCLUSION

As a generalization, we inevitably sacrifice information and geographic precision as we go from 1st order soil surveys to the 5th. How much we sacrifice depends on the

complexity of the soil pattern in nature and on the skill of the scientists making the soil surveys and the interpretations. How damaging these incremental losses are, depends on the purpose or purposes for which the soil surveys are made in the first place.

LITERATURE CITED

KLINGEBIEL, A. A., and P. H. MONTGOMERY. 1961. Land capability classification. U.S. Dept. Agric. Handbk. No. 110. U.S. Govt. Printing Office, Washington, DC.

LAWRENCE, C. B., et al. 1976. Soil survey of Lexington County, South Carolina. U.S. Govt. Printing Office, Washington, DC.

MINISTÉRIO DA AGRICULTURA, DEPARTAMENTO DE PESQUISAS E EXPERIMENTAÇÃO AGROPECUÁRIAS, DIVISÃO DE PEDOLOGIA E FERTILIDADE DO SOLO. 1966. Mapa esquematico dos solos das regioes norte, meio-norte e centro-oeste (primeira aproximação). Ministério da Agricultura, Departamento de Pesquisas e Experimentação Agropecuárias, Divisão de Pedologia e Fertilidade do Solo. Rio de Janeiro, Brazil. (1 sheet, scale 1:5,000,000). (Explanatory text published in 1975 for this map and 3 interpretive maps as Minist. Agric., De. Nac. Pesqui. Agropecu., Div. Pesqui. Pedol. Bol. Tec. No. 17. Rio de Janeiro, Brazil.)

UNITED STATES DEPARTMENT OF AGRICULTURE. 1977. Soil Survey Manual, Rev. ed. (4th draft, 1974–75.)

UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. U.S. Dept. Agric. Handbk. No. 436. U.S. Govt. Printing Office, Washington, DC.

Soil Potentials and Their Use by Planners[1]

National Soils Handbook—Part II

D. Slusher

404 Soil potential ratings

Definition. Soil potential ratings are classes that indicate the relative quality of a soil for a particular use compared with other soils in a given area. Yield or performance level, the relative cost of applying modern technology to minimize the effects of any soil limitations, and the adverse effects of continuing limitations, if any, on social, economic, or environmental values are considered.

Soil potential ratings have been adopted as a form of soil interpretations:

- To provide a common set of terms, applicable to all kinds of land use, for rating the quality of a soil for a particular use relative to other soils in the area.
- To identify the corrective measures needed to overcome soil limitations and the degree to which the measures are feasible and effective.
- To enable local preparation of soil interpretations, using local criteria to meet local needs.
- To provide information about soils that emphasizes feasibility of use rather than avoidance of problems.
- To assemble in one place information on soils, corrective measures, and the relative costs of corrective measures.
- To make soil surveys and related information more applicable and easily used in resource planning.
- To strengthen the resource planning effort through more effective communication of the information provided by soil surveys and properly relating that information to modern technologies.

Soil potential ratings help decision makers determine the relative suitability of soils for a given use. They are used with other resource information as a guide to making land use decisions. Soil potential ratings are used primarily for planning purposes and

[1]This paper presents Part II of Section 404, *Soil Potential Ratings,* of the National Soils Handbook now being drafted by the Soil Conservation Service of USDA.

are not intended as recommendations for soil use. Corrective measures listed are general guides for planning and are not to be applied at a specific location without onsite investigations for design and installation.

To develop soil potential ratings a systematic procedure is required to identify (a) measures for overcoming soil limitations, (b) the performance level of the soils, and (c) limitations continuing after corrective measures have been applied. This procedure must also provide for the use of a numerical system to derive a soil potential index and soil potential ratings. The information assembled is presented to users in soil map unit descriptions, tables, or maps.

The number of soil uses for which ratings are prepared varies from area to area. The importance of the soil use and the number of users of the information must both be considered. When preparing soil potential ratings for a given soil use, all soils in the area should be rated for that use. Soil potential ratings for all soil uses will seldom be needed in a given area.

The geographic area for which soil potential ratings are prepared is an area of importance to a particular group of users. The ratings are mainly to meet needs at a county or subcounty area but can be for any geographic area.

Soil potential ratings are prepared for soil map units regardless of map scale or composition of a unit. Components of multitaxa map units can be evaluated separately if needed to supplement the overall evaluation of a map unit. The soil uses for which soil potential ratings are prepared should be consistent with the detail of mapping.

The procedures in this section have been prepared as guides with contributions from specialists of many disciplines and cooperating agencies. Experience in their use will result in refinements and improvements that may result in revisions to this handbook. Systematic procedures are provided and the end product is defined. A maximum of flexibility is provided. Those who prepare soil potential ratings must be realistic, use good judgment, and be able to adapt the system to conditions and situations in their area.

404.1 Interdisciplinary involvement

Soil uses for which soil potential ratings are prepared can be broadly categorized as agricultural and nonagricultural. For any use, the evaluations of soil potential must be made in collaboration with specialists in fields most closely related to that use.

(a) Agricultural uses. Agricultural uses include various farm crops, pastureland, rangeland, woodland, orchard, wildlife, etc. Ratings of soil potential for these uses help meet the needs of farmers and ranchers, conservation districts, planning commissions, government agencies, or other users of soil interpretations. Soil scientists, agronomists, foresters, soil conservationists, economists, engineers, range conservationists, biologists or others in local, state, or Federal agencies, or private enterprise are called on as needed to provide the expertise for preparing soil potential ratings for agricultural uses.

(b) Nonagricultural uses. Dwellings, roads, waste disposal, and sanitary facilities, etc., even when used on farms, are considered non-agricultural uses. SCS and conservation districts inform units of government and other agencies of the usefulness of soil potential ratings and encourage their preparation. SCS personnel provide leadership in the procedures and assist in identifying the properties of each kind of soil and the composition of soil map units. Technical experts from outside SCS, working closely with SCS specialists, must have a major role and concur in decisions on performance

standards, the means and feasibility of overcoming soil limitations, and the indexes for the costs of corrective measures and the continuing limitations. They must concur in the criteria, the numerical values derived, and the breakpoints between rating classes. SCS coordinates this activity to insure that soil properties are properly identified, that the array is internally consistent in terms of soil properties, and that systematic procedures are followed.

(c) Steps in preparation of ratings. The following steps are suggested as a logical sequence for preparation and presentation of soil potential ratings.

1. Inform users, determine their needs, and initiate action.
2. Identify the technical specialists who will participate.
3. Hold conferences to review procedures and evaluate adequacy of data.
4. Collect additional data is needed.
5. Prepare soil potential ratings.
6. Review and approve ratings as needed.
7. Prepare ratings in final format.
8. Distribute ratings and train users.

404.2 Collection of data

Before soil potential ratings can be prepared for a particular use, data must be available on the properties of the soils, the limitations the soil properties impose on the use, the composition of the soil map units, the kinds of corrective measures needed, the relative cost or difficulty of overcoming the limitations, if any, continuing after given practices are installed, and the level of performance. Many of the data needed are available in technical guides. Other data needed can be collected through observations made and recorded in the course of day-to-day activities or through systematic efforts of SCS personnel, cooperating agencies, local experts, or others.

The data needs must be appraised before soil potential ratings are prepared. If data are insufficient, a plan must be prepared for obtaining the needed information. The data needed, the individuals responsible for their collection, and the target dates for completion must be identified.

404.3 Definition of soil potential classes

Relative terms are assigned to classes to indicate the potential of a soil for a particular use compared with that of other soils in the area. The same soil in a different area may have a different rating for a given use. The rating classes do not identify the most profitable soil use or imply recommendations for soil uses. A soil rated as having high potential for both woodland and cropland may be much more profitable in one use than in the other.

Five classes are provided for comparative ratings of soil potential: very high, high, medium, low, and very low. Very high potential is assigned to only those few soils having properties that make them exceptionally well suited to the particular use. Very low potential is assigned only to soils having properties so unfavorable for the use that they are virtually unsuited. The number of classes used in the final ratings depends on the range of potentials in the area and the degree of refinement needed. Three classes are enough for many areas.

In a few places only two classes of soil potential are needed because all soils in the area are either well suited or poorly suited to the use. It may be important to prepare soil potential ratings, however, to identify widely different kinds of treatments that are

needed for different soils. If a wide array of potential is not present, only two rating classes may be needed; for example, high and medium or medium and low. Ratings of the potential of individual soils are generally not needed in those areas where all soils have the same rating for a given use.

Those preparing the ratings, by establishing the local standards, control the highest or lowest rating class in which a soil in the area can be placed. For example, if corn is not well adapted, then the best rating class for the area might be no better than medium. Another example might be an area where the best soils for dwellings would have medium potential because of high building costs. Thus, a rating of "high" may be avoided if it is felt that it is misleading. Similarly, if all soils in an area are well suited to a use, a "low" potential rating might have an undesirable connotation.

The rating classes are defined in terms of the production or performance expected of a soil if feasible measures are taken to overcome its limitations, the cost of such measures, and the magnitude of the limitations that remain after measures have been applied. Production or performance of each soil is compared with a standard established locally for each soil use (see Section 404.5). The following class terms and definitions are for nationwide use:

Very high potential. Production or performance is at or above local standards; because soil conditions are exceptionally favorable, installation or management costs are low and there are no soil limitations.

High potential. Production or performance is at or above the level of local standards; costs of measures for overcoming soil limitations are judged locally to be favorable in relation to the expected performance of yields; and soil limitations continuing after corrective measures are installed do not detract appreciably from environmental quality or economic returns.

Medium potential. Production or performance is somewhat below local standards; or costs of measures for overcoming soil limitations are high; or soil limitations continuing after corrective measures are installed detract from environmental quality or economic returns.

Low potential. Production or performance is significantly below local standards; or measures required to overcome soil limitations are very costly; or soil limitations continuing after corrective measures are installed detract appreciably from environmental quality of economic returns.

Very low potential. Production or performance is much below local standards; or there are severe soil limitations for which economically feasible measures are unavailable; or soil limitations continuing after corrective measures are installed seriously detract from environmental quality or economic returns.

404.4 Soil uses and kinds of soil map units

Soil uses for which soil potential ratings are prepared should be consistent with the detail of mapping. Soil potential ratings for broad categories of soil uses, such as cropland, woodland, rangeland, or residential land, are appropriate for all levels of soil surveys regardless of the kinds of components that make up the soil map units. Ratings for the more specific soil uses, such as strawberries, avocados, dwellings, or septic tank filter fields, are appropriate for soil map units named as phases of soil series.

Soil potential ratings for the more specific soil uses are seldom appropriate for broadly defined soil map units consisting of associations of phases of series and phases of families or other high taxa. The principle of restricting interpretations for the more

specific soil uses to soil map units consisting of phases of soil series should be generally followed. Soil potential ratings for broad categories of soil use are more appropriate for soil surveys in which the map units are broadly defined.

404.5 General concept of the soil potential index

The soil potential index (SPI) is a numerical rating of a soil's relative suitability or quality. It is used to rank soils from high to low, according to their potential. The SPI is derived from indexes of soil performance, cost of corrective measures, and costs established for continuing limitations. The SPI can be expressed by the equation:

$$SPI = P - (CM + CL)$$

where

P = Index of performance or yield as a locally established standard.

CM = Index of costs of corrective measures to overcome or minimize the effects of soil limitations.

CL = Index of costs resulting from continuing limitations.

All index values used are of a general nature. A highly detailed economic analysis of costs and returns is not required.

The values for CM and CL must be on the same basis. If CM is on an annual basis, CL must also be on an annual basis. If CM is based on the total initial cost of corrective measures and CL is known only on an annual basis, then economic analysis is required to derive common values for comparison. Once a common basis is established for costs of CM and CL, they can be reduced to index values. The SPI can be based on a percentage of the cost or any other base desired.

(a) Performance or yield standard (P). P is an index of a performance or yield standard for the area. It is established and defined locally. The actual yield or performance of each soil is then compared to the standard. For some soils, the yield or performance level will exceed the standard. If so, SPI is adjusted upward on worksheets to reflect the higher yield or performance for the soil [Exhibit 404.6(c) (1), No. 1]. Substandard yield or performance is taken into account as a continuing limitation cost (CL).

In most situations, the standard chosen for P is above the performance level of the average soil in the area but it may be below that achieved on the very best soils. For example, a standard for corn in Bartholomew County, Indiana, might be set at 120 bushels per acre even though on a few of the very best soils this yield is exceeded. This is a performance index, and all soils in the area are evaluated by using this level of P in the equation. For soils that yield above the standard of 120 bushels per acre, SPI is increased by the amount the yield exceeds the standard. For example, for a soil with an estimated yield of 132 bushels per acre:

where P is 120, increase SPI by 12 (132 minus 120);

where P is 100, increase SPI by 10 $\left(\frac{132-120}{120} \times 100\right)$[2]

[2]In these cases, an index value of 100 is used to represent a yield of 120 bushels per acre.

For soils with yields less than the standard, the lower yield is considered a continuing limitation (CL) equal to a factor representing the amount the yield is below the standard. For example: for a soil with an estimated yield of 98 bushels per acre (where P is 100), CL is increased by 18 $(\frac{120-98}{120} \times 100)^2$ to account for the lower yield that is not overcome by corrective measures. These values or their equivalents if some other relative index is used are entered on worksheets for calculations of SPI.

Whether the crop is grown annually or less often because of need for crop rotation must be considered when defining P. The need to include in the rotation crops with low returns can be accounted for by increasing CL. P need not be an absolute measure such as estimated yield.

For structural measures for which performance is not measured in tons, bushels, cubic feet, or other yield levels, P is set at 100 or some other value that serves as a workable index.

(b) Cost of corrective measures (CM). CM is an index of added costs above a defined standard installation or management system that is commonly used if there are no soil limitations that must be overcome. At the standard level, the value of CM is zero; i.e., no deductions would be made in deriving SPI. In unusual situations where a soil is so uniquely suited that costs incurred to obtain the desired level of performance are less than the standard, CM may be a negative value and thus increases SPI.

Examples of costs of corrective measures for agricultural uses are those for terraces or drainage systems. Costs for such measures can be converted to an annual basis for index values compatible with values for P and CL. Whether or not the corrective measures have already been installed is normally not considered, unless it is determined locally that costs already incurred for major irrigation, drainage, or flood control projects should be disregarded.

Added expenses for measures such as increasing the size of a septic tank filter field, strengthening a foundation, or construction grading for site preparation are examples of corrective measure costs for nonagricultural uses. In many cases these kinds of costs may be handled as total initial costs rather than as prorated annual costs. [See Section 404.6(c)(1)(vi).]

Wherever possible, corrective measures are to be identified that will at least partially overcome soil limitations. Management techniques, as well as agronomic or engineering practices, are considered corrective measures. If wetness affects woodland harvest and drainage is not feasible, it is preferable to show, for example, scheduling of logging operations for dry seasons as a corrective measure rather than showing a continuing limitation of a wetness problem with no solution. An important aspect of the procedure for preparing soil potential ratings is that SCS or cooperating agencies assist in identifying technologies that are or, in the opinion of local experts, should be considered workable options locally. Also, we assist the local experts in properly relating those technologies or measures to kinds of soil.

(c) Cost of continuing limitations (CL). Limitations continuing after corrective measures have been applied are those that have adverse effects on social, economic, or environmental values. Distinctions between the three kinds of values need not be made. Continuing limitations that affect returns or profits are clearly economic. Those that result in pollution of air or water are social and environmental effects. CL is an index of costs resulting from such soil limitations.

Continuing soil limitations may be of three types (1) performance such as low yields; inconvenience; discomfort; probability of periodic failure; limitations resulting from the size, shape, or accessibility of an area; or associated soils that restrict a soil's use periods; (2) annual or periodic maintenance costs such as pumping to remove excess water, irrigation, maintenance of drainage or terrace systems, or pumping and removal of septic tank wastes; and (3) offsite damages from sediment or other forms of pollution. [See Section 404.6(c)(1)(vii).]

Examples illustrating the derivation of CL:

— If the local performance standard is 2,000 pounds per acre, a potential production of only 1,500 pounds per acre from rangeland in a normal year, obtained through use of all feasible corrective measures for yield increase, is substandard by 500 pounds. Where P is 100, an appropriate index value for CL is 25.

$$\left(\frac{2000-1500}{2000} \times 100\right)$$

— If flooding of a dwelling remains a probability after feasible measures are installed, an estimate of damage and inconvenience from a flood event divided by the frequency of flooding might provide an annual cost for conversion to index values. For example, damages of $6,000 might be estimated to result from floods occurring 1 year in 10. This represents an annual cost of $600 and a serious continuing limitation. An appropriate value for CL might be 60 if the index for P is 100.

Other values for CL are estimated on the basis of the costs to insure against damage (i.e., flood insurance), costs of maintenance, costs of substitute facilities during periods of malfunction, penalties that might result from offsite or environmental damages or combinations of these and others. Assignment of a cost index to some continuing limitations is of necessity arbitrary.

404.6 Procedures for preparation

An early step in the procedures for preparing soil potential ratings is the assembly and evaluation of soil-related data on yield, performance level, local corrective measures, and limitations that continue after treatments are applied. Published soil surveys, soil handbooks, technical guides, research data, and information from sanitarians, contractors, builders, developers, and others are potential sources of data. The amount of useful data varies from area to area depending on the extent of soil use for a particular purpose.

(a) Selection of uses for which soil potential ratings will be prepared.

(1) *Soils used extensively for the purpose being evaluated.* Deriving SPI is most direct and most accurate if the soils have been used extensively for the purpose or crop being evaluated. The needed corrective measures are well known. The actual performance or yield represents an integration of the effects of corrective measures and soil properties and is also well known. Thus, there is no need to infer or derive relationships among properties, measures, and yields to arrive at the indexes.

(2) *Soils not used for the purpose evaluated.* If soils are being evaluated for purposes for which they are not now used or are used in only a few places, then it is necessary to infer corrective measures and the other indexes that are needed. There are two basic approaches for such derivation.

If similar soils are used for the purpose being evaluated, the evaluations are based on the performance of the similar soils and the corrective measures needed to overcome their limitations. Adjustments can be made to slightly raise or lower the performance level or to modify the measures to account for properties more or less favorable than those of the similar soils.

If information on corrective measures and actual performance of similar soils is not available, those soil properties that affect the particular use are identified and the soils are evaluated on the basis of proved relationships between properties and performance. If this approach must be used, careful consideration should be given to whether ratings are needed or appropriate.

(b) Defining soil use, performance standards, and criteria for evaluation. The soil use must be defined, evaluation criteria prepared, and a local performance standard established [Exhibit 404.6(b), No. 1 and 2]. The definition sets further the conditions under which the soil potential ratings apply. In effect, the definitions state the assumptions under which the ratings apply; they must be carefully considered. Examples include:

— For rating cropland, the kinds of crops grown and basic management systems used;
— for dwellings, the density or size of lots;
— for septic tank filter fields, whether or not a municipal water supply is assumed;
— for numerous uses, the kind or size of equipment used, or methods of procedures followed in the installation of corrective measures.

A performance standard is established and included as a part of the definition.

Evaluation criteria are prepared that list the soil, site and other factors that affect the use [Exhibit 404.6(b), No. 1 and 2]. External features, such as size and shape of area, occurrence in relationship to other soils, regulations, and significant map unit inclusions or nonsoil areas such as rock outcrops that are characteristic of map units, may be included as factors.

The soil factors selected are those that affect yield or performance, require corrective measures, or create limitations to use. Those factors that are considered in rating taxonomic units by degree of limitation (National Soils Handbook, Section 403), are sufficient for some uses. For other uses, criteria for map units may be needed in addition to those for taxonomic units.

For each soil factor, a range of conditions that is related to the kind and relative cost of corrective measures needed to overcome or minimize the effect of the limitation [Exhibit 404.6(b), No. 3] is established. It may be helpful to assign degrees of limitations to each. If so, the coordinated ratings from the Soil Interpretations Record (SCS-Soils-5) are used. For some uses or some factors selected as evaluating criteria, coordinated soil limitation ratings are not available. For these, limitation ratings can be assigned locally. However, ratings of degree of limitation that have not been coordinated are not presented to users in text or tables even though they may have been used in preparing soil potential ratings. For some factors, it may be necessary to subdivide the ranges in properties used for rating soil limitations. For example, in evaluations for dwellings, slopes greater than 15 percent may need to be subdivided as 15–30, 30–50, and 50–80 percent. Even though all these slope classes present severe limitations, differences in the kinds and costs of corrective measures and continuing limitations may be significant for soil potential ratings.

(c) Evaluating map units dominated by phases of soil series. To illustrate one approach to a systematic procedure for preparing soil potential ratings, a worksheet is attached [Exhibit 404.6(c)]. Separate sheets are used for each map unit and for each soil use. Worksheets are to be prepared by states. Copies of completed worksheets are retained in SCS offices as documentation of the procedures used.

(1) General instructions for completing worksheets. General guidance for completing worksheets is given in this section. Examples of completed worksheets are provided for woodland [Exhibit 404.6(c)(1), No. 1]; for septic tank filter fields [Exhibit 404.6(c)(1), No. 2]; and for dwellings without basements [Exhibit 404.6(c)(1), No. 3].

(i) Map unit. Enter the name of the map unit. Soil potential ratings are prepared for the map unit whether a multitaxa or single taxon unit. Separate worksheets are suggested if two or more taxonomic units are named, but the final index for the unit depends on indexes of the components and the size, extent, and relationship of each component to another. Methods of properly integrating ratings of two or more taxonomic units into a rating for the soil map unit are to be prepared locally and must be documented for each soil map unit.

(ii) Evaluation factors. For each use enter on the worksheet the factors that affect the use as identified in the criteria for evaluation [Exhibit 404.6(b), No. 1 and 2].

(iii) Soil and site conditions. For each soil enter the class or range of each soil property or factor used as an evaluation factor; for example, shrink-swell — high; textural class — loam or sandy loam; unified soil classification — SM; and depth to bedrock—20 to 40 inches.

(iv) Degree of limitation. (Optional). If limitation ratings are assigned they can be entered here. Such ratings may be of particular value to individuals outside SCS who are assisting with the ratings. If limitations are not used, then indicate in some way that a soil factor presents an adverse effect and requires further consideration in the evaluation.

(v) Effects on use. Factors rated as moderate or severe limitations or those indicated by other means impose one or more adverse effects on the performance or the installation of the facility, for example, erosion, surface seepage, equipment limitations, reduced yield, foundation failure. Enter the nature of these effects on the use or installation if no precautions or corrective measures are applied. List only the major effects that require correction.

(vi) Corrective measures. For each effect list one or more kinds of corrective measures that will overcome or minimize the effect of the soil limitation and enter the cost index. For example, measures to overcome the effect of a high water table on soybeans might be to delay planting until the water table recedes, to install tile drainage, and/or to provide drainage land grading. The same measure may overcome two or more limitations. If so, enter the cost index for that measure only once.

For soils with slight limitations, it may be desirable to identify a measure or set of measures to provide users with a complete list for all soils. "Conventional system" for septic tank fields and "conventional design" for foundations are examples. The standards for the conventions are set forth in the definition of the soil use.

As a general rule, no corrective measures are given for soils having slight limitations because these soils generally represent the standard. For some uses, however, there are variations in standard installations even though only slight limitations exist and it may be desirable to identify them. For example, because of variations in percolation rates, there is a significant difference in the size of septic tank filter fields required for

soils having slight limitations. Entries on worksheets might show "conventional system, small field" or "conventional system, medium field" to make this distinction.

An index of the costs of corrective measures to overcome limitations is a major factor in assessing soil potential. Significant ranges of measure costs can be established and index numbers rather than actual dollar values can be assigned [Exhibit 404.6(b), No. 2]. This procedure can provide adequate distinctions between measure costs, provide for ease in evaluation, and avoid the implication of great precision. Cost indexes can be based on prorated annual costs, initial installation costs, or other systems, provided that they are expressed in units from the same scale that is used in the indexes for performance and continuing limitations.

It may also be helpful to prepare a set of locally derived corrective measures applicable to specified soil conditions, and their cost. Exhibit 404.6(b) No. 3 illustrates this procedure, but the corrective measures and costs shown are examples only and should not be used in preparing soil potential ratings without local modification.

(vii) Continuing limitations. Regardless of the corrective measures applied, a soil limitation may continue to cause problems because of maintenance cost, substandard performance, or offsite environmental effects. Low yields, maintenance of water disposal systems for erosion control or drainage, use restriction on steep slopes, and maintenance or adequacy of flood control systems are examples. Identify continuing limitations that are associated with alternative measures and indicate by a key phrase the kind of limitation remaining. Assign an index number from a set of values compatible with those used for the performance standard (P) and the measure costs (CM). For some soils, the properties responsible for substandard yields may not be known. If this is so, note the substandard yield as a continuing limitation without relating it to an evaluation factor and enter a cost index for CL [Exhibit 404.6(c)(1), No. 1, Cadeville soil].

(viii) Summary. For each corrective measure (CM) required to overcome an unfavorable soil factor, select the practical and locally accepted corrective measure and the local cost index for the measure and sum.

Sum the indexes for continuing limitations (CL) in the same fashion. Deduct the cost index for the measure (CM) and the cost index for the continuing limitation (CL) from the performance standard index (P) to determine the soil potential index (SPI) as illustrated in the worksheets in Exhibit 404.6(c)(1). Increase SPI as necessary to account for a performance or yield level that is above the standard [Exhibit 404.6(c)(1), No. 1., Quachita soil].

(2) Assignment of ratings. All map units are arrayed from high to low according to their soil potential index. The relative ranking of soils is evaluated againstlocal knowledge. If inconsistencies exist the values used to arrive at SPI should be reevaluated.

To arrive at rating classes, divide the final numerical array on the basis of the definitions of rating classes (Section 404.3) and the tendency of numbers to cluster around certain ranges or show natural group separations [Exhibit 404.6(c)(1), No. 1]. It may not be desirable to indicate the numerical ratings to users since they may indicate a greater degree of refinement than can be defended.

(d) Evaluating broadly defined soil map units. For broadly defined soil map units, such as soil complexes, soil associations, or map units dominated by taxa above the series level, soil potential ratings are generally prepared only for broad categories of soil uses (Section 404.4). In the evaluation for such uses, consideration is given to one or more

of the individual elements that make up the use. For example, the elements of residential soil use might be dwellings, local roads and streets, and shallow excavations. The following steps are suggested:

— List the elements of the use being evaluated.
— List significant component soils and their extent in each map unit.
— Rate each component for each element of the use according to the guides given for phases of soil series.
— Evaluate the map unit for the use according to the evaluation of each element for each component, giving due consideration to the extent and landscape relationship of each of the components.

*(e) **Dealing with regulations.*** Local regulations can affect the development of soils for some uses. If the regulations apply uniformly to certain units, they can be included in rating criteria. For example, if soil potential ratings are being prepared for cropland and regulations prohibit drainage of wetlands, it may be appropriate to include the regulated conditions as one of the rating criteria. In such cases, however, it must be possible to distinguish between wetland and nonwetland map units. A preferred alternative is to prepare the ratings as if there were no regulations and footnote worksheets and final presentations to indicate those soils on which the use is prohibited by regulations.

Dealing with regulated uses such as sanitary facilities that require approval by regulatory agencies need not be troublesome. Consideration of the alternatives and agreement on the procedures with those for whom soil potential ratings are being developed can result in useful soil potential ratings.

404.7 Terminology for limitations and corrective measures

Ratings of soil potential are to be accompanied by a statement of the corrective measures required to overcome soil limitations. Broad categories of corrective measures are suggested for use with ratings for broad categories of soil uses and more specific corrective measures for the more specific uses. Choice of phrases or terms can best be determined locally on the basis of the properties of the soils and the kinds of corrective measures needed. The following examples of limitations, broad categories of corrective measures, and more specific corrective measures illustrate the differences but are not intended to dictate specific terms for use.

Limitations	*Broad Categories of Corrective Measures*	*More Specific Corrective Measures*
Wetness	Drainage	Surface drainage Tile drainage Drainage land grading
Steep slope	Construction grading	Cuts and fills
Erodes easily	Erosion control	Permanent vegetation Grassed waterways Terraces Conservation tillage

High shrink-swell	Strengthened foundation	Reinforced slab Extended footings Moisture control
Floods	Flood control	Raised foundation Dikes Improved channels
Low strength	Supported foundation	Widened footings Extended footings Slab foundation
Droughty	Irrigation	Sprinkler irrigation Furrow irrigation Border irrigation

404.8 Format for presenting soil potential ratings

Soil potential ratings must be effectively presented. All presentations must include the explanation of ratings (Exhibit 404.8, No. 1) and local definitions of the rating classes (Section 404.3). Definitions of soil uses must also be included. Regardless of the method of presentation, the worksheets and criteria for evaluation that were used must be retained in the SCS office as documentation of the procedures. Participating agencies and names of technical specialists who participated, in addition to SCS specialists, are identified in all publications. Soil potential ratings are not presented without concurrence by the agency or agencies for whom they were prepared and who participated in their preparation. Soil potential ratings are not to be used by SCS unless the systematic procedures outlined in this handbook are followed.

Presentation may be in the narrative form, as in soil map unit descriptions, or in tables. As a minimum, all tables and discussions must identify the soil potential rating and the corrective measures needed to achieve the potential of each soil map unit (Exhibits 404.8, No. 2, 3, and 4). The most desirable format identifies the soil factors that adversely affect the use, the corrective measures, and a statement of any continuing limitations (Exhibit 404.8, No. 2). If soil limitations are presented in conjunction with soil potential ratings, as in Exhibit 404.8, No. 2, they should not be repeated for the soil use in other tables in the report.

The tables shown in Exhibits 404.8, No. 2, 3, and 4, can be modified to meet local needs as long as minimum content is included.

An example of a narrative statement in a map unit description of a phase of a soil series is as follows:

> This soil has high potential for septic tank filter fields if the field size is increased to compensate for the slow percolation rate.

A narrative statement in a map unit description of an association might be as follows:

> This association (or map unit) has high potential for residential use if foundations are strengthened and drainage is provided on Alpha soils or if dwellings are placed only on Beta soils.

Ratings for soil potential can be shown on colored maps, but they must be supported by tabular or narrative presentations that identify the corrective measures needed to achieve the potential and provide definitions of the soil uses and rating classes.

EXHIBIT 404.6(b) No. 1

Soil potential ratings for woodland (Beta County)

Definition: Soils managed for maximum average yearly growth per acre (cubic feet) assuming established stands for loblolly pine if adapted, otherwise the best adapted hardwood, not fertilized or irrigated. Yield standard = 130 cubic feet per acre average yearly growth.[a]

Evaluating Criteria:

	Degree of Limitation[b]		
Factors Affecting Use	*Slight*	*Moderate*	*Severe*
Slope (percent)	0–15	15–25	25–40
Depth to water table (feet)	>2.0	2.0–0.5	<0.5
Flooding	None or rare	—	Common
Available water capacity (inches per 5-foot depth)	>8	8–5	<5
Surface texture	Loamy	Sandy and clayey	—

Cost Index: A percentage of the value of the harvested crop rounded to the nearest whole number is used. Cost classes representing ranges of values are not used.

Performance Index: 100 (equivalent to the yield standard of 130 cubic feet per acre per year).

[a]The yield standard of 130 cubic feet per acre per year is set on the basis of the production of a locally preferred species (loblolly pine—site index 90) on good soils that are also extensive. As the most productive trees (preferred species) on some soils may be oak or some other hardwood, cubic feet per acre provides a more consistent measure of yield than site index. Standard yield tables are available to convert site index of specific trees to cubic feet per acre.

[b]Assignment of degree of limitation is optional; however, classes reflecting different levels or costs of corrective measures are helpful. The ranges under slight limitations will represent the standard or base level for which no corrective measures are given.

EXHIBIT 404.6(b) No. 2

Soil potential for dwellings without basements

Definition: Single family residences; 1400 to 1800 square feet of living area; without basements; spread footings and/or slab construction; life span 50 years; and intensive use of yard for lawns, gardens, landscaping, and play areas. Ratings assume adequate waste disposal and lot sizes of one fourth acre or less.

Evaluating Criteria:

	Degree of Limitation		
Factors Affecting Use	*Slight*	*Moderate*	*Severe*
Depth to water table (inches)	>30	18–30	<18
Flooding	None	None	All
Slope (percent)	0–8	8–15	>15
Shrink-swell potential	Low	Moderate	High

Cost Index:

Index value[a]	*Cost classes for corrective measures and continuing limitations (dollars)*[b]
1	<250
2	250–500
4	500–1000
8	1000–2000
12	2000–3000
16	3000–4000
20	4000–5000

Performance index: 100

[a]Index values in this example are arbitrarily set at 0.4 percent of the upper limit of each cost class.

[b]To be compatible with costs of corrective measures the cost of continuing limitations is established for the 50 year life span of the dwelling.

EXHIBIT 404.6(b) No. 3

List of corrective measures and costs for dwellings without basements
This exhibit shows how local data might be summarized and made available as a ready reference for preparing soil potential ratings. Corrective measures likely to be needed can be anticipated and costs established for each. As soil potential ratings are prepared, additional measures may be identified that should be added to the list. The general technique can be applied to both agricultural and nonagricultural soil uses.

This example is only to illustrate a procedure. Corrective measures and costs illustrated are examples only and should not be used without modification to fit local situations.

Corrective measures are those to overcome or minimize soil limitations identified in evaluating criteria. Costs are based on an arbitrary local standard foundation area of approximately 1200 square feet and are those in excess of standard design where no soil limitations are identified. Index values are one percent of estimated costs.

Corrective Measures	*Cost (dollars)*	*Index*
Drainage of footing	300–500	4
Drainage of footing and slab	600–800	7
Excavation and grading		
8–15 percent slopes	100–300	2
15–30 percent slopes	300–500	4
Rock excavation and disposal (fractured limestone)		
0–8 percent slopes	1000–1400	12
8–15 percent slopes	700–900	8
Reinforced slab		
moderate shrink-swell potential	1500–2000	17
high shrink-swell potential	3600–4200	39
Areawide surface drainage (per lot)	100–200	2
Importing topsoil for lawn and garden	1000–1400	11

Examples of application of cost index:

a. Soil on 8 to 15 percent slopes with high shrink-swell potential requires:

Reinforced slab		39
Excavation and grading		2
CM	=	41

b. Soil on 0 to 1 percent slopes with high water table requires:

Areawide surface drainage		2
Drainage of footing and slab		7
CM	=	9

Worksheet for Preparing Soil Potential Ratings

Exhibit 404.6(c)(1)

Soil Use: **Area:**

Mapping Unit:

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects On Use	Corrective Measures		Continuing Limitations	
				Kinds	Index	Kind	Index
				Total		Total	

______ − ______ − ______ = ______

Performance Standard Index − Measure Cost Index − Continuing Limitation Cost Index = Soil Potential Index[a]

[a] If performance exceeds the standard increase SPI by that amount.

EXHIBIT 404.6(c)(1) No. 1

Explanation of worksheets for preparing soil potential ratings (Woodland-Beta County)

A worksheet is prepared for each soil map unit.

The yield standard (130) is adjusted to a performance standard index of 100 to provide a range of soil potential indexes from 0 to 100. Productivity of 130 cubic feet per acre (loblolly pine, site index 90) meets the performance standard index of 100, e.g., the Guyton and Ruston map units. Productivity of 100 cubic feet per acre (loblolly pine, site index 80) is substandard performance $100/130 \times 100 = 85$ and is considered a continuing limitation if corrective measures fail to overcome the yield limitation, e.g., the Alaga and Cadeville map units. Productivity of 152 cubic feet per acre (loblolly pine, site index 100) is performance above the yield standard (Ouachita map unit). To reflect this yield level SPI is increased by 17 ($152 - 130/130 \times 100 = 17$).

Enter evaluation factors from table of rating criteria prepared for the soil use (Exhibit 404.6(b) No. 1).

Enter soil and site conditions for the map unit for each evaluation factor. Enter the degree of limitation from the table of evaluation criteria (Exhibit 404.6(b), No. 1).

Enter effects of the soil and site conditions to serve as a basis for identification of corrective measures.

Enter feasible alternative measures for overcoming the effects of limiting soil or site conditions. Technical guides are useful references. Note that measures are identified wherever possible to overcome effects of limitations in preference to carrying the problems on the unresolved continuing limitations.

In this example, index values for measures and continuing limitations are a percentage of the value of the harvested crops. Whether the costs occur only one time or several times in the period between planting and harvest is considered.

The factor that accounts for substandard yield of the Cadeville soil is not known. The substandard yield is noted as a continuing limitation without relation to a soil factor.

Index values for corrective measures (CM) and continuing limitations (CL) are summed for deduction from the performance standard index (P) to determine the soil potential index (SPI).

The soil potential indexes are arrayed from high to low and ratings assigned as follows:

SPI	*Rating*	*Soil Map Unit*
116	Very high	Ouachita silt loam
100	High	Ruston fine sandy loam, 1 to 3 percent slope
85	High	Guyton silt loam
78	Medium	Alaga loamy fine sand, 8 to 13 percent slope
77	Medium	Cadeville fine sandy loan, 15 to 25 percent slope

Worksheet for Preparing Soil Potential Ratings Exhibit 404.6(c)(1)

Soil Use: Woodland **Area:** Beta County

Mapping Unit: Alaga loamy fine sand, 8 to 13 percent slopes

Yield standard 130 ft³/ac/yr
Yield estimate 110 ft³/ac/yr

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects On Use	Corrective Measures		Continuing Limitations	
				Kinds	Index	Kind	Index
Slope (percent)	8-13%	Slight	None				
Depth to high water table (ft.)	> 5'	Slight	None				
Flooding	None	Slight	None				
Available water capacity (5 ft. depth)	< 5"	Severe	Reduced yield; Seedling mortality	None occasional replant	2/ 0 4	Moderate yield	3/ 15
Surface texture	Sandy	Moderate	Equipment limitation	Special equipment or schedule operations to avoid dry seasons	3		
				Total	7	Total	15

2/ Index values are a percentage of the value of the harvested crop.

3/ Yield reduction is 15 percent of the standard $\left(\frac{130-110}{130} \times 100\right) = 15$

100	−	7	−	15	=	78
Performance Standard Index		Measure Cost Index		Continuing Limitation Cost Index		Soil Potential Index[a]

[a]If performance exceeds the standard increase SPI by that amount.

Worksheet for Preparing Soil Potential Ratings Exhibit 404.6(c)(1)

Soil Use: Woodland **Area:** Beta County

Mapping Unit: Cadeville fine sandy loam, 15 to 25 percent slopes

Yield standard 130 ft^3/ac/yr
Yield estimate 110 ft^3/ac/yr

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects On Use	Corrective Measures		Continuing Limitations	
				Kinds	Index	Kind	Index
Slope (percent)	15-25%	Moderate	Equipment limitation, erosion	Safety precautions 2/ Road design	4 3	None Road maintenance	 1
Depth to high water table (ft.)	> 2'	Slight	None				
Flooding	None	Slight	None				
Available water capacity (5 ft. depth)	> 8"	Slight	None				
Surface texture	loamy	Slight	None			Moderate yield 3/	15
				Total	7	Total	16

2/ Special equipment not considered practical

3/ Substandard yield not accounted for in evaluation factors. Corrective measures not known. Yield is 15% below standard.

Performance Standard Index		Measure Cost Index		Continuing Limitation Cost Index		Soil Potential Index[a]
100	−	7	−	16	=	77

[a] If performance exceeds the standard increase SPI by that amount.

EXHIBIT 404.8 No. 1

Explanation of soil potential ratings for use with maps or reports

The soil potential ratings indicate the comparative quality of each soil in the county for the specified uses. Because comparisons are made only among soils in this county, ratings of a given soil in another county may differ.

The ratings are based on a system developed for this county that included consideration of (1) yield or performance levels, (2) the difficulty or relative cost of corrective measures that will improve soil performance or yield, and (3) adverse social, economic or environmental effects of soil limitations, if any, that cannot be feasibly overcome.

The ratings do not constitute recommendations for soil use. They are to assist individuals, planning commissions, and others in arriving at wise land use decisions. Treatment measures are intended as a guide to planning and are not to be applied at a specific location without onsite investigations for design and installation.

The soil potential ratings used are defined as follows:

(To be followed by the definitions of those soil potential ratings used.)

Table 1. Soil potential ratings for septic tank filter fields.

Soil name and map symbol	Limitations and restrictions	Soil potential and corrective treatment	Continuing limitations
1. Grenada silt loam, 0 to 2 percent slopes	Severe: percs slowly.	Medium: conventional system, alternate valve, large field, pump tank in wet season.	Monitor system for need to pump.
2. Jefferson gravelly loam, 5 to 12 percent slopes	Slight	Very high: conventional system, small field.	None
3. Linsdale silt loam, 0 to 2 percent slopes	Severe: wetness.	High: conventional system, medium field, area wide subsurface drainage.	Maintain drainage system.
4. Memphis silt loam, 2 to 6 percent slopes	Slight	High: conventional system, medium field.	None.
5. Memphis silt loam, 12 to 20 percent slopes	Moderate: slope.	High: conventional system, medium field, slope design.	None.
6. Memphis silt loam, 25 to 30 percent slopes	Severe: slope.	Very low: no known system.	—
7. Talbott silt loam, 8 to 12 percent slopes	Severe: percs slowly, depth to rock.	Low: mound system.	None.
8. Waverly silt loam, 0 to 2 percent slopes	Severe: wetness.	Low: mound system.	None.

Exhibit 404.8
No. 2

Table 2. Soil potential ratings for cropland.

Soil name and map symbol	Soil potential and corrective treatment	Continuing limitations
1. Caddo silt loam, 0 to 1 percent slopes	High: drainage, high fertilization rate.	Maintenance of drainage system.
2. Gore fine sandy loam, 8 to 12 percent slopes	Low: erosion control.	Maintenance of erosion control system, substandard yield.
3. Guyton silt loam	Medium: drainage, high fertilization rate.	Maintenance of drainage system.
4. Guyton silt loam, frequently flooded	Very low: project type flood control, drainage.	Maintenance of drainage and flood control system.
5. Kisatchie soils, 15 to 30 percent soils	Very low: erosion control, high fertilization rate.	Maintenance of erosion control system, equipment limitations; substandard yield.
6. Norwood silt loam	Very high: drainage.	Maintenance of drainage system.
7. Ruston fine sandy loam, 3 to 5 percent slopes	High: erosion control.	Maintenance of erosion control system.
8. Ruston fine sandy loam, 8 to 12 percent slopes	Low: erosion control.	Maintenance of erosion control system, substandard yield.

Exhibit 404.8
No. 3

Table 3. Soil potential ratings and corrective measures for cropland, pastureland, woodland, and residential land.

Soil name	Cropland	Pastureland	Woodland	Residential land
1. Caddo silt loam, 0 to 1 percent slopes	High: drainage.	High: drainage, scheduled grazing to avoid wet conditions.	High: scheduled operations to avoid wetness.	Medium: drainage.
2. Gore fine sandy loam, 8 to 12 percent slopes	Low: erosion control.	Medium: erosion control.	Medium: scheduled operations to avoid wet conditions.	Medium: construction grading, water disposal, strengthened foundations.
3. Guyton silt loam	Medium: drainage.	Medium: drainage, scheduled grazing to avoid wet conditions.	High: scheduled operations to avoid wet conditions.	Low: drainage, diversions.
4. Guyton silt loam, frequently flooded	Very low: project type flood control.	Low: drainage, adapted water tolerant plants, scheduled grazing to avoid wet conditions.	High: scheduled operations to avoid wet conditions	Very low: project type flood control, drainage.
5. Kisatchie soils, 15 to 30 percent slopes	Very low[a]	Low: reduced stocking rate.	Low: erosion control during site preparation and logging.	Low: construction grading, water disposal excavate rock.
6. Norwood silt loam	Very high	Very high	Very high	Very high
7. Ruston fine sandy loam, 3 to 8 percent slopes	High: erosion control.	Very high	High	Very high
8. Ruston fine sandy loam, 8 to 12 percent slopes	Low: erosion control.	Very high	High	High: construction grading, water disposal.

[a]Soil conditions are such that treatments are generally not warranted for this use.

Utilization and Presentation of Soil Resource Inventory Information for Land and Water Resource Planning

Luvern L. Resler

Food production continues to be one of the most pressing problems of the world. Considering population projections, even greater increases in food requirements throughout the world can be expected. University representatives from Arizona, California, Colorado, and Utah, who make up the Consortium for International Development, state:

> "The green revolution, while providing a potential for important food supply increases, cannot reach that potential without substantial and sustained improvements in the management of available water and soil resources." (Consortium for International Development, 1975.)

This statement is especially true in the arid and subhumid areas of the world where there is insufficient precipitation to support a viable rainfed agriculture, but also has implications regarding rainfed agriculture.

The arid and subhumid regions comprise approximately one-sixth of the total land surface and a substantially greater portion of the world's potential for agricultural production. Full-service irrigation or systems for supplemental water service will have a leading role to play in meeting the food and fiber requirements generated by the world's population increase.

The Bureau of Reclamation recognizes that irrigation places special demands on conservation of our land and water resources. These demands arise because irrigation, along with other of man's activities, causes changes in the environment. As we alter the amount, quality, timing, and place of water use, we change the physical, chemical, and biological systems operating within the soil and sub-strata, and impact the broad environmental and social spectrum. The immediate changes are normally favorable, thereby fulfilling needs, providing new opportunities, and improving the standard of living and social well-being of the people. On the other hand, the long-term effects, which have been experienced by some developments, have been to degrade or destroy land resources. This can be avoided.

In the Bureau of Reclamation, it is recognized that to accomplish sound, acceptable resource planning and project development, a multi-disciplinary team approach is

required. The many facets and complex interactions involved with naturally occurring land and water systems make it imperative that open communication channels be established and maintained between cooperating-planning team members. Much of the study team's success depends upon the integration, organization, coordination, and knowledgeable information exchange that is involved in the activities of several disciplines including plant science, water suitability science, hydrology, drainage, engineering, environmental sciences, sociology, geology, soil science, and economics relative to land and water management. Therefore, information developed from gathered data needs to be pertinent to the problem-solving efforts and usable by all planning team members and decision-making bodies.

Planners of resource development projects have a social obligation and moral responsibility to assure that the changes brought about by their actions will be favorable over the long run.

LAND CLASSIFICATION

Land resource investigations in the Bureau of Reclamation are conducted primarily to define land areas capable of sustained, profitable agricultural production under irrigation. Irrigation suitability land classification is thus the systematic appraisal of lands and their designation by categories or classes on the basis of similar physical and chemical characteristics and related economic implications and conditions with respect to suitability for permanent, productive irrigation agriculture. A land classification survey is an economic and physical delineation of land into categories or land classes that ultimately represent repayment capacity or net farm income. The land classification investigations include other related land uses within a given project setting and their impacts upon nonproject areas.

To establish adequate background information and form a firm foundation upon which to build an understanding of land classification's specific needs, the following two definitions and associated terminology commonly used will be beneficial.

Arable land

Arable land, when farmed in adequately sized units for the prevailing climatic and economic setting and provided with the essential onfarm improvements such as removing vegetation, leveling, soil reclamation, drainage, and irrigation-related facilities, will generate sufficient income under irrigation to pay farm production expenses; provide a reasonable return to farm family labor, management, and capital; and at least pay a portion of the operation, maintenance, and replacement costs of associated irrigation and drainage facilities.

Land class

Land class is a designation for a body of land having soil, topography, and drainage characteristics resulting in a similar economic level of suitability for irrigation within a specific project setting. Land classes are mutually exclusive; i.e. pertinent factors are arranged in discrete, nonoverlapping, and determinate groups or divisions in the classification. Individual land classes are defined within a specific project setting, normally using three classes of arable land and one nonarable class.

Class 1. Lands suitable for sustained high yields of most climatically adapted crops under sustained irrigation with minimum costs of development and management associated with the land.

Class 2. Lands of moderate productivity, or requiring moderate costs for development and management because of slight-to-moderate limitations in land characteristics.

Class 3. Lands of restricted productivity for most crops, or lands requiring relatively high costs for development and management because of moderate-to-severe limitations in land characteristics.

Class 6. Lands which are unsuited for sustained irrigation due to excessively severe limitations in soils, topography, or drainage for a particular project setting.

These major classes, along with the associated subclasses evaluating land deficiencies, accommodate the normal land classification study needs.

Land classification focuses on a specific system for the production of food and fiber through irrigated agriculture. Land classification cannot and should not be directly applied by following a set of general landclass-determining factors or rules. Each potential project setting presents its own particular land classification requirements. The landscape complex, climatic variances, and the broad variety of economic, social, and institutional factors render the specification of a rigid system impractical. Land classification surveys should, therefore, be designed and land classes defined to meet specific development goals and economic requirements relevant to each project.

Therefore, formal static rules or regulations concerning the Bureau's system of land classification do not constitute a major portion of the body of information related to irrigation planning study applications. In this system of land selection for permanent, profitable water and land resources development, a set of basic principles has evolved that does have general application and can be used in perfecting a dynamic classification system for local specific needs. The principles have applicability to broad aspects of agronomic development, rainfed agriculture as well as irrigation.

Principles of land classification

The land classification resource planning survey should adhere, to the extent possible, to the time-tested classification principles (Bureau of Reclamation, 1953; Maletic, 1962; Maletic and Hutchings, 1967; Peters, 1975). These principles have been developed to guide the establishment of the specific classification system for selecting lands for a particular plan of development. In developing irrigation projects, land and water resources should be efficiently combined by an engineering and settlement plan that best meets defined, realistic, and attainable social and economic goals of the people.

Lands selected for development should be permanently productive under the change in environmental regime anticipated with irrigation. The introduction of irrigation shifts the natural balance established over time between water, land, vegetation, fauna, and man. Irrigation project planning, therefore, identifies and evaluates the changes, and the plans are formulated to assure that a successful, permanent agriculture will result. Principles that control classification of the potential project system may be identified as (1) prediction, (2) economic correlation, (3) arability-irrigability analysis, and (4) permanent-changeable factors.

Prediction principle. The land classes must express predictions of future soil-water-crop interactions expected to prevail under the new moisture regime resulting from the

project. This involves identifying and evaluating the changes anticipated from water control, supply, drainage, and overall management relative to formulating plans to assure that a successful, permanent agriculture will result.

As with most of man's other agronomic activities, irrigation induces changes in the physical, chemical, and biological characteristics of the land. Many of the changes are interrelated and complex. It is not sufficient to just describe existing land characteristics and conditions. The process of data collection and synthesis into information should include prediction of the changes that will occur. Soil structure may be modified by changes in salinity, modification of exchangeable sodium percentage (ESP), variation of organic matter content and regimen, and alteration of clay minerals. Irrigation may induce shallow water table development, causing drainage problems and related salinity; changes in sodium concentrations and aeration conditions which influence crop growth; modification of slope and microrelief by landforming, and alteration of soil profile characteristics by deep plowing, chiseling, or addition of amendments. The irrigation water may cause favorable changes in the salinity of the soil through leaching or an unfavorable increase in salinity through high water tables or insufficient application of irrigation water. Depending upon water electrolyte concentration and ion species, the exchangeable sodium level of the soil may equilibrate at levels favoring water movement through the soil or it may increase, causing some soils to become impermeable. Calcium carbonate and gypsum may be precipitated or dissolved. Organic matter levels will change and new biological populations will develop in the soil.

Flooding a soil, as practiced under rice cultivation, instantly sets in motion a series of physical, microbiological, and chemical processes which influence crop growth. These include retardation of gaseous exchange between soil and air, reduction in the soil system, and the electrochemical changes accompanying the reduction. Carbon dioxide and other gases (nitrogen, methane, hydrogen) produced in the soil tend to accumulate, build up pressure, and escape as bubbles. There is a decrease in redox potential, potential change in pH, and an increase in specific conductance. Also the flooding causes denitrification; accumulation of ammonia; reduction of manganese, iron, and sulfate; accumulation of the decomposition products of anaerobic microorganisms; and other secondary effects of reduction.

In accomplishing land classification surveys for selecting lands suitable for irrigation, the planning effort should include provisions for recognition and evaluation of the changes that will occur. This will require not only careful field studies of observable soil characteristics and qualities but also detailed measurements of the relevant attributes of the soil and substrate in the field and in the laboratory. Special problems may arise during the investigation of the land resources. Appropriate solutions must be brought to bear upon solving the problem. This would include cooperation between various disciplines in federal, state, and local institutions and organizations well versed in basic and applied research.

It may require the establishment of research projects or the operation of development farms to test the compatibility of the soil and water and derivation of suitable cropping and management systems.

Economic correlation principle. In any particular project setting, the economic correlation principle states that the physical factors of soil characteristics and land conditions, including topography and drainage, are functionally related to economic parameters. A relative economic return will be realized when a specific parcel of land is put into production. Understanding some of the interrelationships and interdependencies

PLANNING PROCESS FLOW CHART

FEASIBILITY INVESTIGATION

Note - The symbol [ERC-P] noting technical assistance and/or review provided by ERC-Planning has been shown where it most likely will be requested.
Assistance may be provided at any point in the planning process.

*Detail of Appraisal-Level Geologic Studies

- Review available geologic maps and literature _ RO
- Field examination of locations of potential facilities _ RO
- Description of geologic conditions of locality sites _ RO
- Prepare appraisal geologic reports, as necessary _ RO

**Detail of Feasibility Grade Geologic Studies

- Review appraisal studies _ RO
- Further review of available geologic maps and literature as necessary _ RO
- Supplement field geologic mapping of potential facility sites, as necessary, either in coverage or greater detail _ RO
- Prepare drilling program _ RO
- Review drilling program if requested by RO _ ERC-D
- Monitor drilling program and log drill holes _ RO
- Field location of construction materials _ RO
- Laboratory testing of drill core and construction materials (as necessary) _ ERC-R
- Study of special factors, such as seismicity, land slide potential, ground water conditions _ RO
- Prepare feasibility geologic reports, with text, maps, sections, drill logs _ RO
- Review of geologic report (with field review by ERC if requested by RO) _ ERC

*** Dam feasibility designs and estimates are normally done at the ERC. Should the feasibility design and estimates be done in the region the procedures D-13 through D-24 shown on the Design Chart are also followed.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DECEMBER 2, 1976

SYMBOL LEGEND

- Process
- Input, Output and/or Review
- Decision
- Inter-Connection with Another Functional Flow Chart
- Terminate Process
- Variable Time
- [ ] By Request - Technical Assistance and/or Review Provided by ERC-P or D

ABREVIATIONS

W	Commissioner's Office
RO	Regional Director
AR	Authorized Representative of the Contracting Officer
DI	Department of the Interior
ERC-	Engineering and Research Center
P	Planning Division
D	Design Division
C	Construction Division
ES	Engineering Support Division
O	Water Operation and Maintenance
E-I-S	Environmental Impact Statement
C-E-Q	Council of Environmental Quality

of economics and soil science, as it applies to the land classification process, helps develop a clearer understanding of some of the economic implications of the judgment decisions land classifiers are required to make. As stated by Nielsen, "The field of economics simply deals with means and ends. Ends are the objectives of people and may deal with net income, consumer satisfactions, or physical production. Means are the physical resources, funds, organizations, or institutions which can be used to attain the various possible ends or objectives."

Economics is a science of choice between the alternatives regarding peoples' objectives and the resources with which they may be obtained. Choices made are influenced by the funds available, financing capabilities, and products or objectives desired.

In water and land resource development the characteristics and qualities of lands that determine suitability for development through modification in water supply, control, management, and use vary with each project. The land-class-determining factors represent selected and correlated ranges for such soil resource inventory characteristics as texture; depth to bedrock, hardpan, sand, gravel, caliche or other root-limiting influences; structure; consistence; color and mottling; kinds and amounts of coarse fragments; and kind, thickness, and sequence of horizons. In addition, the prediction aspect of selecting arable lands requires quantifying laboratory and field measurements. Performance qualities are also either measured where possible or inferred. These would include factors such as fertility, productivity, erodibility, and drainability, as well as such measurable factors as infiltration rate, hydraulic conductivity, moisture characteristics, and moisture-holding capacity (Peters, 1977). If a pertinent land parameter is quantifiable, it should be measured rather than estimated.

In some systems of land classification the economic value is not critically defined—it may be merely implied in a qualitative manner usually in terms of anticipated productivity levels. In other systems such as that used by the U. S. Bureau of Reclamation the economic value is defined as payment capacity—the residual available to defray the cost of water after all other costs have been met by the farm operator (Bureau of Reclamation, 1953). Thus the major determination for development is between lands that are economically viable for development (arable) from those which are not (nonarable). Therefore, arable land is land which "when farmed in adequately sized units for the prevailing climatic and economic setting and provided with the essential onfarm improvements of removing vegetation, leveling, soil reclamation, drainage, and irrigation-related facilities will generate sufficient income under irrigation to pay all farm production expenses; provide a reasonable return to the farm family's labor, management, and capital; and at least pay the operation, maintenance, and replacement costs of associated irrigation and drainage facilities."

When land classes are defined as economic entities, then relevant and mappable land characteristics are chosen at a given time and place to comprise the set of land-class-determining factors. The class-limiting value of these physical characteristics will vary with the economic, ecological, technological, and institutional factors prevailing or expected to prevail in the area. As a consequence, land classes will express a local ranking of the lands for irrigation use. They may represent lands best suited, moderately suited, poorly suited, and unsuited for irrigation development. The physical basis for the ranking is adapted to the specific project environment. For example, in the northwestern United States lands with slopes up to 35 percent may be well suited for irrigation while on the Gulf Coastal Plain of Texas lands with slopes over 3 percent would be unsuited for irrigation. The differences are caused primarily by intensity of

rainfall. In areas producing high economic returns more severe deficiencies in factors such as structure, texture, salinity level, sodic level, drainage, and microrelief can be tolerated than in areas producing low returns. Also social and political goals oftentimes dictate the degree of economic input desirable for agricultural development. An example might be irrigation project development in an economically depressed area to create more jobs for people, or in a country with ample funds available for development and a desire to be self-sufficient in food production.

Permanent and changeable factors principle. The permanent-changeable factors principle recognizes that for each setting there are land features and characteristics which will not be changed under irrigation and those which will, and that it is necessary to identify those which will be significantly altered. This identification, through economic studies and recognition of the land characteristics, permits establishment of a consistent set of specifications assuring uniform appraisal of land conditions in making the land classification survey. Most land factors, including soil depth, are changeable at a cost. Typical changeable factors include salinity, sodicity, titratable acidity and exchangeable aluminum, depths to water table, relief, brush and tree cover, rock cover, drainage, and flood hazard. It's not how "good" or how "bad" a resource is but what can be done with it.

Whether given characteristics will be changed usually depends upon economic considerations. The land classification survey must deal with two aspects of this principle. Can the change be accomplished, and what degree of change is economically feasible? This is largely dependent on the climatic and economic setting of the project.

Arability-irrigability area analysis principle. The arable area-irrigable area analysis principle relates to the procedure for selection of lands to be served and involves a two-step process. In the initial step, the arable area (land with sufficient farm productivity to warrant consideration) is identified. The second step involves the selection of the irrigable area, those lands capable of being served with irrigation water, from those lands determined to be arable and to be included in the plan of development. The selection of arable lands is based upon a determination that the land is capable of sustaining economically viable family farm operations under irrigation, assuming water control is provided. Water control may involve drainage in a humid area or water supply in an arid area. The selection of the irrigable area is guided by goals and objectives selected to guide plan formulation. The scope of plans is influenced by purposes and objectives to be served by a plan.

The application of plan formulation and evaluation criteria to the classification generally leads to successive elimination of identifiable increments of arable lands from the plan of development. Typical adjustments include: (1) elimination of noneconomic increments such as those that are too costly to serve, drain, or manage; (2) conformance of land area to utilizability, serviceability, and manageability; (3) exclusion of isolated segments, odd-shaped tracts, and severed areas that cannot be efficiently fitted into the farm unit pattern; (4) deletion of proposed public rights-of-way; and (5) exclusion of land areas that would contribute excessive salinity or other undesirable constituents to return flows. Of these factors, items (1) and (5) are goal-dependent.

Water suitability. In general, water quality evaluations may be approached by analysis of the environmental setting of the project in the context of predicted future water use. The suitability of water involves integrating land and water factors. In this process, land classification surveys are utilized to delineate land classes that would

favorably respond to a water supply of a given quality. This selection of land as a potential part of development is then tested as to feasibility by application of plan formulation criteria.

Water quality standards per se are not applied in appraising the usability of water for irrigation. "Its usability depends on what can be done with the water if applied to a given soil under a particular set of circumstances. The successful long-term use of any irrigation water depends more on rainfall, leaching, irrigation water management, salt tolerance of crops, and soil management practices than upon water quality itself" (Fireman, 1960).

LAND SELECTION PROCEDURE

The most important phase of reclamation land classification is the separation of those lands which are suitable for irrigation development under the prevailing conditions from those which are not. This is the arability determination and is the initial step in the selection of land to be served for irrigation. The arable area remains constant and serves as the base from which the irrigable area is selected and provides a source of land data for use by other disciplines involved in the study.

Planning, developing, and maintaining water and land resources for agricultural production mainly involves providing control of water, both soil and groundwater. This is accomplished through installation and operation of facilities and implementation of measures; i.e. water supply and distribution, water and land use, management, and drainage. Formulation of plants can be efficiently guided by an effective system of economic land classification. The general principles followed in the Bureau of Reclamation are applied to fit land classification to the specific environmental situation including economic, social, physical, cultural, and legal patterns existing in the area.

The principles described provide a basis for organizing land classification and related techniques into a process that permits selection of irrigable land within a specific project setting. Provision is made for coordinating the engineering, agricultural, economic, social, environmental, and other aspects of irrigation project development. In applying these principles, the Bureau of Reclamation (1953) has identified the various steps involved in performing the land classification survey. The steps are more or less related and should be developed concurrently to the extent that available information will permit. Methodology should be developed for application to local needs using the principles previously discussed. In several countries, there has been a tendency to adopt rather than adapt; i.e. to attempt transfer of procedures rather than develop systems based on the principles. Usually, the transfer approach will not work satisfactorily; thus it is essential to go through the rigors embodied in applying the principles.

In preparing for the land classification study, the matter of handling land development costs is determined. Methodology may vary between countries according to whether the government expects the farmer or landowner to pay for all development costs or if the government does all of the on-farm development with no direct cost to the farmer. Land classification is varied to show a reduced payment capacity in net farm income and lower land class where land development costs are borne by the farmer. When development costs are handled as a government expense, they do not influence the land class except when the maximum permissible expenditure would be exceeded.

Major types of land classification for project plan formulation include: (1) appraisal, (2) feasibility, (3) advanced planning (definite plan and preconstruction), (4) special studies, and (5) postconstruction. Of these, feasibility grade classifications are of primary importance in the planning process, and represent a standard by which other types of studies may be compared.

It is important that the type of land classification conducted, amount of detail, and accuracy required be consistent with the purpose of the investigation and be governed by the primary applications intended. All types shall be guided by amount of detail needed and the accuracy objective. This is governed by the relation of the mapping units, i.e., land classes, subclasses, and boundaries, to the features that are useful and significant to plan formulation of the irrigation project.

Generally, appraisal surveys are brief, preliminary studies mainly utilizing existing data. A feasibility survey is conducted to determine whether a project is worthy of construction and, if found worthy, to provide information for Congressional authorization in the plan of development utilized in the United States. An advanced planning survey is made in support of project construction and certification as to the adequacy of land classification studies in fulfillment of the Bureau of Reclamation's technical and legal responsibilities.

Appraisal studies

Appraisal surveys are used to select areas which seemingly have development potential; thus they are a general delineation of lands suitable for irrigation. The detail of mapping is such that relative land quality designations will indicate, as a minimum, separation of arable lands for general farming or specialty crop areas from nonarable areas. The factors considered in an appraisal land classification study are generally the same as those considered in a feasibility study, but the quantity of data available is less, delineations are less precise, and the allowable degree of accuracy is lower. Generally, a minimum of field investigations are made, and a great degree of reliance is placed upon existing data or secondary or indirect sources of information. Irrigation method should be clearly specified for each appraisal study. Where different methods are required, an estimate of the area adaptable to each method will need to be developed. Water suitability for the involved lands along with drainage and return flow factors will be part of the study.

Feasibility studies

The feasibility survey deals with the question of whether or not the project is worthy of construction. It shall provide land resource data of sufficient reliability and accuracy to make sound judgments and recommendations needed for decision-making regarding prospects for proceeding with authorization and development. This requires careful examination of land features to assure reasonable accuracy in the identification and delineation of arable and nonarable lands. A reasonably accurate determination of the overall area and associated land classes of projects or separate segments should be provided. Basic data with respect to soil and subsoil conditions, topography, and drainage shall be obtained in sufficient detail to meet the accuracy objective and to provide the additional land data required for drainage, return flow studies, and other investigational needs.

The land classes shall be based on the economics of production and the manner in which land development costs are handled within specific areas. Hence, the produc-

tion and repayment potentials may differ significantly among such areas. All classes will not necessarily be found in any given agricultural setting. Three basic arable classes are normally used in the Bureau system to identify the arable lands according to their suitability for irrigation agriculture. Class 1 land has the highest level of irrigation suitability, hence the highest payment capacity. Class 2 has intermediate suitability and payment capacity. Class 3 has the lowest suitability and payment capacity. There are situations where Class 4 arable class is used to represent lands of very limited repayment potential that would only cover operation and maintenance costs. Two nonarable classes may be used: Class 5 lands are nonarable under existing conditions, but have potential value sufficient to warrant tentative segregation for special study prior to completion of the classification; and Class 6 lands are considered nonarable under existing project plans because of failure to meet the minimum requirements of at least paying operation, maintenance, and replacement (OM&R) costs as required for arable classes.

The number of classes mapped in a particular investigation depends upon the diversity of the land conditions encountered and their reflection in potential farm income. Four arable classes may be used in high-income areas, but only one class may be justified in situations where crops are limited to low income production due to climate or other land characteristics. For each project, land class determining factors are selected and identified consistent primarily with national or agency policy and economic setting of the project.

Advance planning studies

Following authorization for development, advance planning detailed investigations are conducted to supply planning information required prior to construction and to serve as the basis for refining arable area delineations. These plans also supply information used in plan formulation, evaluation, canal sizing, determining farm unit water allotment, and repayment. Land use needs, other than for irrigation, which were established during the feasibility study are reexamined and firmed up during the preconstruction stage of investigations.

Special studies

Study conditions may require land inventory investigations. These may be considered as a special type of appraisal land classification study. In some investigations, it is necessary or desirable to inventory lands within a given area which are capable of sustained production under irrigation. This inventory, where economic analyses are lacking, may be based upon physical and chemical characteristics irrespective of the economic feasibility analysis applicable to appraisal studies. In these cases, the requirement that arability implies an ability for the land to provide a reasonable return to the farm family as well as sufficient remaining income to at least pay OM&R costs under a specific plan of development is not necessarily applicable; instead, arability as used here implies only that the land if served with irrigation water is capable of sustained production of crops adaptable to the area at a level of yield considered normal for other irrigated lands of the general area.

Requirements for detail and types of data collected may vary but are generally similar to those outlined above for appraisal studies. Land inventories will normally be made only in cases where insufficient data exist to establish firm economic criteria or anticipated plans of development such as river basin investigation, or in situations where economics as normally used may have other applications.

Postconstruction surveys

Postconstruction surveys are undertaken as required to accommodate changes in land classification resulting from actual construction. This normally involves adjustments with respect to exclusions and inclusions to the irrigable area. Exclusions and inclusions that may occur are changes in the service area affected by the allocated water supply and rights-of-way for canals, laterals, drains, and roads.

A final determination of irrigable lands cannot be made until farm unit boundaries have been established and the location and extent of facilities such as public roads, laterals, turnouts, and drainage facilities are established. This is usually done during the advance planning stages of investigation; but, because of changes in the system during construction, a review is usually necessary to adjust the irrigable area. Because these factors were considered in the initial establishment of the irrigable area, any corrections which may be necessary in determining the final irrigable lands should be relatively small.

At the end of the development period, a review of the irrigable area will be necessary to make final adjustments resulting from land development, changes in system, and "squaring" of fields. This will be the official project irrigable area to be used in the determination of contract requirements such as construction charges and water allotments.

PLANNING LAND AND WATER RESOURCE DEVELOPMENT

To improve and maintain sound economic bases for the general well-being of a population or the overall quality of life is an objective that ranks among the most important and rewarding of our day. The overriding consideration throughout multiobjective plan formulation, at all levels, is to reflect society's preferences for three major national objectives which are defined broadly as:

National Economic Development (NED)

The purpose of this objective is to increase the nation's output of goods and services and improve economic efficiency.

Environmental Quality (EQ)

This objective would be to enhance the quality of the environment by the protection, management, conservation, preservation, creation, restoration, or improvement of the quality of certain natural or cultural resources and ecological systems.

Regional Development (RD)

The objectives here would be to increase regional income and employment; distribution of population; improve the regional economic base and educational, cultural, and recreational opportunities; and enhance environmental conditions of the region and other specified components (Bureau of Reclamation, 1972).

As identified in multiobjective planning, the "well-being of people" is fundamental and cuts across the three objectives (op. cit.). In all instances social effects must be considered. The extent to which land and water planning efforts contribute either in a beneficial or adverse way in serving the three objectives, as well as impacts upon or by social factors, must be evaluated to provide the means of appraisal of projects and

tradeoffs among alternatives. Thus benefits and costs are evaluated either in monetary or nonmonetary terms for the four accounts: NED, EQ, RD, and social factors.

All plans, regardless of which objective is being emphasized, will have impacts on all four accounts that must be measured to the best of the planner's ability considering the detail of the study, the data base, and available procedural techniques (op. cit.).

Agencies involved in water and land resources planning and development normally consider joint use to serve such purposes as flood control, irrigation, municipal and industrial water supply, hydroelectric power, recreation, and fish and wildlife. It is also normal that agencies and requisite professional disciplines may inadvertently accentuate some purposes of development at the expense of others. Therefore, it is imperative that all the relevant disciplines' endeavors be coordinated and study efforts and results be mutually analyzed and, through interchange, a joint developmental approach reached.

The planning process flow chart that follows presents in a graphic way the interrelationships among requisite disciplines in relationship to time and accomplishments during the planning effort. This information is specific with respect to feasibility stage planning efforts within the Bureau of Reclamation but has application for consideration at other stages of the planning sequence.

Following an appraisal study and the determination of the need for feasibility grade investigations, again representative of federal, state, county, local government, associations and interested private groups, and individuals are invited to review previous work. Prior studies and future project direction plans are totally committed to open public participation. A refinement or redefinition of land and water developmental problems and needs must be accomplished through public involvement and application of sound multidisciplinary technical study procedures.

Soil resource inventory information, as it relates to specific land classification needs, along with accumulated lands data, are reviewed and applied to the identification of all alternatives to be considered. Additional lands data are collected in accordance with guideline specifications in the light of social, economic, and engineering study needs aligned with land classification requirements. Land classification studies have direct interactions with other requisite disciplines relative to: (1) water supply needs and appraisals, (2) appraisal of the future with and without project conditions, (3) social impact estimates, (4) economic and financial appraisal of alternatives, (5) project facilities layouts, (6) design and estimates of serving facilities, (7) formulation of alternative plans, (8) environmental study impacts and needs, and (9) final selection plans for additional studies.

Following completion of feasibility grade field investigations, data are compiled, analyses made, and interpretations and conclusions presented in feasibility reports covering all the study needs. This information is again routed through the public information program, any changes or additions considered, and following requisite reviews the proposals are submitted for legislative decision for construction authorization.

The general collection, presentation, and utilization of land resource data and information development, including soil resource inventory information, continues from the appraisal investigations through feasibility and preconstruction studies and is a part of the postconstruction and postdevelopment needs of land and water resource projects. The information generated is applicable to inventory requirements including: (1) irrigable land, (2) water management, (3) land use and size of farms, (4) land

development, (5) payment capacity, (6) irrigation benefits, (7) irrigation and drainage systems, (8) land appraisal, (9) irrigation assessments, (10) environmental assessments, (11) return flow water quality, and (12) social impacts.

The fundamental requirement of the classification system addressed in this report is to define, for the time, place, and economic and social setting, what is to constitute a finding of irrigability and then to establish principles and procedures for land classification that permit a critical selection of the irrigable lands. Irrigation presents a unique capability with great promise for the future of many people. Planners have a moral duty and a technical responsibility to apply skillful planning techniques founded upon sound concepts of land and water use.

LITERATURE CITED

Bureau of Reclamation. 1953. Manual, Vol. V—Irrigation Land Use; Part 2—Land Classification. Bureau of Reclamation, U.S. Dept. of the Interior, Washington, D.C.

Bureau of Reclamation. 1972. Guidelines of implementing principles and standards for multiobjective planning of water resources. Bureau of Reclamation, U.S. Dept. of the Interior, Washington, D.C.

Consortium for International Development. 1975. Water and soil management in irrigated regions—a prospectus. Utah State University, Logan, UT.

Fireman, M. 1960. Quality of water for irrigation. University of California Extension Service, Davis, CA.

Maletic, J. T. 1962. Principles involved in selecting lands for irrigation. Paper presented at the International Seminar on Water and Soil Utilization, South Dakota State Univ., Brookings, SD.

Maletic, J. T., and T. B. Hutchings. 1967. Selection and classification of irrigable land. *In* R. M. Hagan, et al. (ed.) Irrigation of Agricultural Lands. American Society of Agronomy, Madison, WI.

Nielsen, A. 1963. Economics and soil science—Copartners in land classification. A paper presented at the USBR Region 7 Land Classification Meeting, February 1963.

Peters, W. B. 1975. Status and results of USAID-sponsored field soil and water management programs. Paper prepared for the Soil and Water Management Workshop sponsored by the United States Department of State, Agency for International Development, Washington, D.C., February 18–21, 1975.

Peters, W. B. 1977. A unifying system of land classification for universal application. Paper prepared for the North Dakota Irrigation Symposium, Fargo, North Dakota, February 17–18, 1977.

Evaluation of Soil Resources by ORSTOM

R. Fauck

Since 1946, Office de la Recherche Scientifique et Technique Outre-Mer scientific workers have drawn up more than a thousand soil maps, from moist tropical forest to Sahelian regions, from Black Africa to the Mediterranean areas, the West Indies and French Guiana, and the Pacific islands. The primary aim between 1946 and 1956 was to catalogue types of soils, often unknown to begin with, and map them on a medium scale (1:200,000). Subsequently, four other types of maps were prepared: two large-scale types for development schemes (1:50,000 and 1:20,000); and two small-scale types for regional planning purposes (1:500,000 and 1:1,000,000). For various reasons, government departments in the countries involved differed considerably in the use they made of these maps. Certain technical services had considerable difficulty interpreting, in development terms, maps and reports written by soil scientists. Aware of this difficulty, ORSTOM prepared new documents to supplement soil maps to provide a clearer definition of soil capabilities. As time has gone by, various methods of presentation have been used. It is the experience of ORSTOM in this area that is described in the following report.

USERS' NEEDS AND DIFFICULTIES IN RESOURCE EVALUATION

The land user's ideal would be to have documents giving, for each soil type, all possible forms of crops and optimum conditions of usage to ensure maximum yield, while preserving natural fertility. For many reasons it is extremely difficult to achieve this objective in most tropical regions.

To begin with, the state of soils knowledge varies widely depending on world regions; but in general, agricultural research does not yet provide all the factors needed to define all the opportunities of use for each type of soil.

Next, assuming that this objective can be achieved, another very important problem involves the wide range of possible farming methods, from the most intensive to the most extensive. Between drip irrigation, drought-animal tilling and the extensive stockbreeding of the Sahelian nomads, there exists a whole series of possible farming methods, which depend mainly on local social and economic factors as time passes. This is impractical, at any rate for soil scientists.

Finally, there is the problem of map scale. There are three scales to be considered: for soil distribution on the ground, for land use by man, and for soil maps. Soil

distribution on the land is closely related to topography and parent material variations. Soil types succeed one another in a toposequence over variable distances: some tens-of-meters in some cases; a few hundreds in others; and thousands of meters are occasionally found. In these circumstances, maps show pure soil units only when they are large-scale or very large-scale. When medium or small-scale, soil units become complex, regardless of the method of classification or taxonomy.

By soil-utilization scale is meant the size of farming units. This factor can vary considerably, from a few acres for the family holding for market gardening, to several thousand hectares for the stock ranch. The method of utilization of soil maps will differ considerably depending on such factors.

Finally, the soil map scale is rarely determined by ground truth, in other words, by the soil-distribution scale. It is sometimes determined by the objective, for example an irrigation scheme or regional planning. But it is usually governed by financial requirements, and in most cases the map scale is much smaller than the soil distribution scale. Consequently, most maps represent complex units, usually soil associations.

An association is a combination of soil types consisting of one dominant soil and its associated soils, which when grouped together often corresponds to a geomorphological unit. An association may comprise soils with very different capabilities, sometimes incompatible with one another. And that is what frequently makes soil maps difficult to use. The concept of capabilities is a complex one: the capabilities of the various soils in an association differ from one another increasingly as agriculture intensifies. On the other hand, for unmechanized agriculture in Sudan regions, involving very little or no fertilizer use, many types of soils could be grouped together. This can be done even if they are labelled differently by soil scientists in order to conform to classification or taxonomic rules, provided that they allow the same range of crops. Differences among these soils will involve the level of yield of the various plants grown, in relation to inputs or farming techniques.

These remarks suggest the separation of two types of factors affecting capability: one factor concerns the suitability or unsuitability of soils for a specific use; and the other factor concerns soil fertility levels in relation to different cultivation methods, and depends on intensiveness and on complexity. The case of suitability or unsuitability involves the concept of limiting factors or utilization constraints. The second case must take into account, for each particular use, soil capabilities in relation to likely inputs and social and economic conditions.

This analysis of users' needs and the difficulties of meeting them in tropical regions explains the decision by French scientists to use different methods of cartographical representation.

SOLUTIONS ADOPTED

Various technical solutions have been adopted; they vary depending on the climatic environment, as well as on map scale. In most cases, however, maps have been drawn on the basis of a conventional soil map. A few examples may be given to illustrate this. A very great number of large-scale soil suitability maps (1:10,000 or 1:20,000) have been produced, for Cameroon, Madagascar, the West Indies, etc. This is the most straightforward case, in which soil units represent a single type, and in which the caption indicates possible uses. Two categories of maps have been established in

Tunisia, one showing suitability for dry farming, and the other suitability for irrigated farming. Together with the soil map, users accordingly have three maps with different legends.

Another method is at present being tried in French Guiana, where soil variability is very high. Soil cover is not characterized by specific contours but by isodifferentiation curves. Toposequences are represented in cross sections or diagram blocks. Agricultural engineering units categorize all soils with the same type of drainage. In view of the major effect of lateral circulation of water in upper horizons, for example on plant rooting and on soil erodibility, this is the characteristic method to categorize soils with a morphology that changes quickly on slopes.

Not many examples exist of medium-scale soil suitability maps based on conventional soil maps. There is, however, the case of a soil-resource map taken from a 1:200,000 soil map, with an agricultural engineering unit key. The method, performed on a small scale (1:500,000), will be described later. On the other hand, maps exist combining geomorphological and soil data and defining wide farming suitability groups. Two systems are being worked out. One of these, produced by Institut Recherches Agronomie Tropicale (Paris), first defines morpho-soil units on the basis of an interpretation of links between morphogenesis and pedogenesis. It then assesses the capabilities of the physical environment, allowing constraint maps and land-allocation recommendation maps to be drawn. The second system, at present being developed by ORSTOM in the Ivory Coast, concerns morphological and soil landscapes to the scale of 1:200,000. Internal drainage, water-holding capacity, percentage of coarse components, and rock depth are given for each unit. Information on agricultural suitabilities is supplied in the text accompanying each map.

For small-scale maps (1:500,000 and 1:1,000,000), it is difficult to define soil-utilization possibilities in a key, because the map includes complex soil units or soil associations. However, planners are interested in such soil maps insofar as they make a useful contribution to the choice if not of crops, at least to possible systems of exploitation. This is why authors of the various maps that have been drawn confine themselves to showing either a wide classification of agricultural qualities (rich, fair, poor), or very general farming possibilities, such as dry farming, irrigated farming, or grazing. A typical example is the 1:1,000,000 map of New Caledonia.

Another method has been tested in Sahelian regions, notably in Upper Volta: the "soil resource map." It is based on dividing soil cover into units suitable for the same type of traditional or extensive farming. Anything is possible in intensive farming, where the soil may be no more than a physical support. For example, let us consider the sand dunes, found over wide areas of the Sahel. It is not recommended that the dunes should be used to grow millet, since this traditional crop results in movement of the dunes by wind erosion. But it would be possible to recommend drip irrigation with the use of fertilizer and manure to grow strawberries, as is done near Dakar. Given the social and economic situation in the Sahel, a 1:500,000-scale map provides only for low-intensive or medium-intensive cultivation, with an emphasis on utilization constraints. These constraints comprise those which cannot be altered by human intervention, and those which can be changed more or less easily. The former constraints include soil depths and textural classes, which govern suitability or unsuitability for a given purpose. The latter include chemical richness, which can be altered by the use of fertilizers; soil water resources, which can be improved by irrigation; and the upper horizon structure, which can be altered by working the soil.

From a practical viewpoint, the method is based on prior establishment of a fertility factor table. Eight soil characteristics have been selected as governing farming capabilities. The order in which they are given is based mainly on the degree of constraint: the first two, depth and texture, are immutable, as mentioned above; the others can be altered by human intervention. Fertility factors are as follows:

1. Available depth: this is not the depth of the soil but the depth that can be reached easily by roots (cf. presence of gravel in many tropical soils).
2. Textural type: this is represented by two textures: the upper horizon and the B horizon (importance of textural variation is for rooting and water dynamics).
3. Existing water economy: this is the available water and its variation in relation to climatic season, namely soil moisture characteristics.
4. Chemical features: these consist of the sum of cation exchanges and base saturation.
5. Deficiencies (e.g. phosphate).
6. Presence of adverse chemical elements (e.g. free aluminum, sulphides).
7. Organic matter: quantity and quality.
8. Adverse physical properties (e.g. sealing).

The fertility factor table was composed by analyzing the references on 1:500,000 soil maps. Next, units were categorized on the basis of soil types ("dominant" types) in the same class for soil depth and textural type (in other words the two inalterable units) on the basis that they represent fairly homogeneous groups for agricultural purposes. It is understood, of course, that the types of "associated" soils that they contain may vary, with different capabilities or at least fertility levels.

This initial soil classification for defining agronomic units is inadequate for planning purposes, since small-scale maps are involved. Soil classified within the same unit — regardless of the method of classification used — may be distributed widely over different climatic zones from an agricultural viewpoint. This is why comparable agronomic units (according to average depth and textural type) have been subdivided on the basis of a third criterion, climatic zonality. The different zones take into account the length of rainy season or seasons, and also average rainfalls. Because of the insufficiency of such data in many regions and the year-to-year variability in Sahelian regions, zone boundaries are somewhat vague.

Ultimately, one obtains a key of agronomic units. Opposite each of the units of this key, there are details of constraints (erodability) and recommendations for land use (fertilizer requirements, working of soil, etc.). In practice, land use planners find out quickly from the map about comparable agronomic units. They then examine the table, which details the eight essential characteristics for each of them, representing fertility factors on the basis of which choice of specific uses may be made. Finally, land users refer to another table, which shows correspondence with soil map units. The reader should consult this soil map and the report accompanying it, first to find out about soil distribution in the landscape (toposequences, associations), and partly to discover the morphological and physico-chemical properties of each of the soils in the association.

Initial reactions from government departments are encouraging. Technicians seem to be less discouraged than in the past by the complexity of soil maps and soil scientist's jargon because of the preliminary reading of soil resource maps. They have therefore been found to meet a need.

CONCLUSIONS

Beek (1978) emphasized the high number of map systems aimed at evaluating soil utilization possibilities. The ORSTOM experiment does not allow any conclusions to be drawn about the advantage of one system over another. The choice must depend first on the scale adopted, second on the accuracy of available data, and finally on the local social and economic framework. Maps are easier to produce on a large scale. But planners often call for small-scale maps, wanting all farming possibilities to be defined for each type of soil, with an indication of the potential fertility level for various hypotheses of extensive or intensive cultivation. This objective cannot be achieved by soil scientists alone; but it would be reached if soil scientists, agricultural experts and economists combined their resources. Unfortunately, the state of agronomic knowledge of the average depth of profiles could involve the elimination of certain crops or their acceptance; the recommendation that mechanized methods should not be used; or accepting the methods with the risk of insufficient yields on a local and economic level—this last factor can vary in time. In addition, the idea of depth is sometimes counterbalanced by the concept of chemical richness, and advances in the development of new varieties further complicate the situation.

The state of affairs and regional planning needs in new African states have led ORSTOM to produce small-scale "soil resource" maps. These supplemental soil maps still have to be drawn. It is not their purpose to propose precise forms of soil utilization, but to stipulate constraints on use. In other words they list limiting or favorable soil factors, with quantitative details of soil erodability and the level of chemical fertility. Definitions of farming methods, which involve technical, social and economic factors, is at a later stage, which for the moment lies in the field of agricultural experts, planners and decision-makers.

LITERATURE CITED

Beaudou, A. G., and V. Collinet. 1977. La diversité des volumes pédologiques cartographiés dans le domaine ferrallitique africain. Cáh. ORSTOM, sér. Pédologie. 15(1):19–34.

Beaudou, A. G., and R. Sayol. 1977. Légende de la carte des paysages morphopédologiques de Boundiali. Centre ORSTOM, Adiopodoumé, Côte d'Ivoire. (Scale 1:200,000). Mimeographed.

Beek, K. J. 1978. Land evaluation for agricultural development. Pub. No. 23. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

Boulaine, J. 1978. Les unités cartographiques en pédologie. Analyse de la notion de Génon. Bull. de l'Association Française pour l'Etude des Sols. No. 1, p. 15–30.

Boulet, R. 1976. Notice des cartes de ressources en sols de la Haute-Volta. Mimeo, ORSTOM, Paris.

Boyer, J. 1975. Les sols ferrallitiques. I. Les facteurs physiques de fertilité. ORSTOM, mimeographed.

Kilian, J. 1975. Etude du milieu physique en vue de son aménagement; Conceptions de travail; Méthodes cartographiques. Agronomie tropicale. 29(23):141–153.

Latham, M., P. Quantin, and G. Aubert. 1978. Etude des sols de la Nouvelle-Calédonie. Carte pédologique et carte d'aptitude culturale et forestière des sols. Notice explicative no. 78. ORSTOM, Paris. (2 maps; scale 1:1,000,000).

Leveque, A. 1978. Ressources in sols du Togo. Carte à 1:200,000 des unités agronomiques déduites de la carte pédologique. Notice explicative no. 73. ORSTOM, Paris.

Muller, J. P. 1974. Aptitude culturales des sols de l'Ouest Cameroun. Notion-establissement et utilisation des cartes. ORSTOM, mimeographed.

Pouget, M. 1977. Region de Messaad-Ain El Ibel. Notice explicative. Cartographie des zones arides: Géomorphologie, pédologie, groupements végétaux, aptitudes du milieu pour la mise en valeur. (4 maps; scale 1:100,000).

Van Wambeke, A. 1978. Problèmes relatifs au maintien de la productivité des sols. Colloque sur l'amélioration des systèmes de production agricole. Bamako, Mali.

PART TWO

ADEQUACY OF SOIL RESOURCE INVENTORIES

Section I

Criteria for Appraising Soil Surveys

Thoughts about Appraising the Utility of Soil Maps

Marlin G. Cline

Soil maps[1] are graphic representations of the geography of sets of soil properties. Depending on the point of view, some would also include maps that show only single soil properties or soil attributes.[2] The maps with accompanying legends and descriptive material are, at best, incomplete records of soil conditions within areas of land. Their potential usefulness depends on the degree to which they accurately represent the geographic distribution of soil conditions that are critical for soil use and management. Their actual utility also depends on presentation in a form that can be used intelligently by those who may wish to apply the information. Both their potential and actual usefulness for a given purpose also depend on the degree to which they satisfy the level of detail or generalization required by objectives of the user.

One must ask two basic questions to appraise soil maps: (1) What does one need to know to appraise the soil itself for use and management? This question is discussed in section II A. (2) To what degree does a soil map and associated material provide the things we need to know? This question is discussed in section IIB.

I. A PROPOSED FORMAT

Appraisals of the utility of soil maps could be presented as a narrative, which would offer advantages of flexibility to identify attributes that would enhance or detract from map utility. If a narrative were used, it should follow a specific outline to insure that relevant aspects are covered. The organization of forms to assist in the interpretation should probably conform with the logic of a narrative outline.

More detailed discussion of concepts and approaches is provided in section II A and B. Section II C describes a methodology that is summarized in the following outline. Any of several outlines or forms could be developed for appraising the utility of soil maps. This individual sees some logic to organization along the following lines. A narrative should give brief, simple statements about each item.

[1]For purposes of this discussion, the term *soil map* includes the map itself, a legend, and any text or tabulated information that defines or describes the area and the map units. *Soil map* is used instead of *soil survey* to include those which are compiled from sources other than field studies.

[2]The term *soil attribute* is used here for characteristics such as soil drainage condition, parent material, fertility, erodibility, and others that are inferred from soil properties observed or measured. Their identification requires one step of reasoning from the properties observed or measured directly.

1. Complexity or simplicity of soil pattern in the field (from item II C3). It would seem desirable to orient potential users quickly to characteristics of the area in nature as background for appraisal of the map. This item might come first in a narrative appraisal or at the beginning of a form.

2. Reliability of information provided (from item II C4). It would appear reasonable to alert users quickly about the degree to which they can or cannot trust the data presented.

3. Size of planning area (from item II C1). This identifies the geographic scope of projects for which the information can be used effectively—and greatly narrows the range of utility. It would appear logical to place this item toward the beginning of either a narrative or form.

4. Size of areas for which soil potentials can be determined within planning areas (from measures of delineation sizes). This tells the user how much or how little geographic detail he can incorporate in his project on the basis of this map. In addition, he should be told:

4a. Proportion of those that are homogeneous for land use (from II C3).

4b. Proportion homogeneous for soil management (from II C3).

4c. Proportion heterogeneous for use and information does not describe pattern of differences within areas (from II C3).

4d. Proportion heterogeneous for soil management but information describes pattern of differences within areas (from II C3).

5. Adequacy of information about soil attributes within map units for identified uses (from II C2). It is this part which would tell whether or not the map can be interpreted for identified uses or management systems. Table 1, or a comparable device, would be a primary source, and could well be included as part of the appraisal. In addition, some explanation would probably be in order, and appraisals for uses not identified on any form one might develop would be needed for some maps. For example, Table 1 provides a checklist for "cultural systems" as a generalization. Presumably, one would check attributes which would be critical for any of the cultural systems one might envisage. Different cultural systems, however, have different soil requirements. If permeability were not known with some specificity it would drastically limit an interpretation for irrigated systems or paddy culture but would be much less serious for interpretations for dryland farming. It is points like this which make a narrative appraisal attractive.

6. Quality of the base map (from II C5). The checklist of section C5 could be used in a form. A simple statement would suffice in a narrative appraisal.

7. Legibility of soil information (from II C6). For this too, a checklist could be included in a form, and a simple statement would suffice in a narrative appraisal.

Guidelines would have to be provided if different people having different backgrounds were to arrive at similar appraisals. The most difficult to provide are those for appraising information about soil attributes within map units for identified kinds and levels of soil use.

One might face the problem of how to appraise the information one may glean from the legend and the text. The attributes revealed by names of taxa would have to be identified for each taxonomic system likely to be encountered. One can visualize a series of tables in which attributes in some kind of list comparable to that of Table 1 would be identified as revealed or unrevealed by taxonomic names. Probably a thorough appraisal would require some system to show the level of information the names imply for each item. Part of this could be analyzed by categories, but in many

Table 1. Information about soil attributes within map units.

Soil Attributes	Broad Land Use Classes	Cultural Systems	Broad Plant Character	Specific Plants	Management
A. Soil Moisture					
1. Soil Moisture Regime					
a. Intergrades					
2. Available Moisture					
B. Soil Temperature					
1. Soil Temperature Regime					
a. Intergrades					
C. Chemical Properties					
1. Colloidal Behavior					
a. Clay Mineralogy					
b. Cation Exchange Cap.					
2. Soil Fertility					
a. Nutrient supply					
b. Nutrient fixation					
3. Soil Acidity					
4. Soil Salinity & Sodicity					
D. Physical Properties					
1. Related to rooting					
a. Aeration					
b. Physical obstruction					
2. Permeability					
3. Tilth Potential					
4. Obstructions to culture					
a. Stoniness					
b. Rock outcrop					
c. Slope gradient					

systems the criteria differ among taxa within categories. If it were necessary to analyze the information implied by each taxonomic name, the task would be very complicated. There may be no good alternative to this.

Another major guideline would entail identifying which of a list of soil attributes is critical for a given category of land use classes at different levels of generalization (such as those identified by headings in Table 1). In Table 1, for example, one could identify which of the soil attributes listed are potentially prohibiting for one or more of the land use classes that would fall under each heading. For the broad land use classes (crops, grazing, forestry), items A1, B1, C4, D1b, D4a, D4b, and D4c are most likely to prohibit cropping in mechanized systems. The other items may affect performance, perhaps drastically. Some of these are subject to correction (a management factor). Depending on assumptions about how much weight to give soil performance and management requirements, the seven attributes given above might be considered the primary requirements of soil maps for this category of uses.

Perhaps more significant would be checklists for specific kinds of use within categories. For the category of broad land use classes, a checklist would probably represent information critical for the most demanding kind of use, namely cropping. The same would apply to each of the other categories. Tables showing attributes that are (1) potentially prohibiting, (2) potentially limiting for performance and difficult to correct, and (3) potentially limiting but feasible of correction could be prepared for each of several bench mark kinds of land use within categories at different levels of generalization.

These are aspects that have not been explored. There may be much simpler approaches, but at this writing some comparable mechanism seems necessary if appraisals are more than subjective judgments. It is likely that more careful consideration of land use categories could lead to much simpler guidelines. No attempt has been made, for example, to identify groups of land use classes, cultural systems, or plants having similar soil requirements. Maps could be appraised for such groups as units.

II A. APPRAISING SOIL ITSELF

The following are at least some of the more important things one needs to know to appraise soil for use and management:

1. The use for which the soil is to be appraised.
2. The level of detail or generalization required by the objective.
3. The soil properties or attributes that are important for this use.
4. The degree of limitations imposed by soil properties or attributes.
5. The distribution of critical soil conditions within the area.

Land use for which soil is to be appraised

Different kinds of land use have different soil requirements. Soil requirements are different for lowland rice, for example, than for coffee or cacao. The need to know the use or uses for which soil is to be appraised is so obvious that it would rarely not be specified for an on-site investigation. Yet many soil surveys are made without clearly defining the purposes for which the information is intended. Some are used incorrectly for purposes for which they were not intended.

Level of detail or generalization

This subject includes (1) the level of generalization of the soil appraisal and (2) the level of generalization of land use classes for which soil potential is to be estimated.

Soil appraisals for different purposes require different levels of geographic detail of information about soils. For some purposes, one only needs to know approximately how much of the soil of areas involving hundreds or thousands of square kilometers has properties that are good, fair or poor for a given use. Precise geographic location of local differences among soils is not important. For other purposes, one needs to know precisely where soils of different potential are found within areas of a few hectares. In an on-site investigation, we can adjust data gathering to fit the geographic requirements of the objective. For soil maps, the geographic detail is fixed, presumably by some preconceived notion of the purposes for which the map will be used. Geographic detail of the map is an important criterion of its utility for different purposes.

Land use can also be conceived at different levels of generalization independently of geographic distribution. For some purposes, one only needs to know the soil potential for broad use groups, such as crops, grazing, forestry, or urban uses. For others, one needs to know soil potential for specific uses, such as wetland rice or dryland wheat. This kind of conceptual detail or generalization of land use may be applied to either very large or very small areas. Many soil appraisals for broad land use groups are made in general geographic terms involving areas hundreds of square kilometers in size. Many judgments are also made, however, about relative soil potentials of areas a few hectares in size for broad land use groups, such as crops, pasture, or woodland. It is also true that, while judgments of soil potential for very specific uses are commonly made for areas the size of individual fields, they are also made for areas of hundreds of square kilometers. Consequently, a system for appraising the utility of soil maps must accommodate a very broad range of combinations of conceptual detail of land use and geographic detail of soil distribution.

Usually when soil potentials are appraised for general land use classes, however, the land use terms imply much broader concepts of land use than is actually intended. An appraisal for "crops" in the temperate regions, for example, obviously excludes crops suited only to the tropics. An appraisal for unirrigated grazing in regions of xeric soil moisture regimes clearly does not consider plants that require summer rainfall. This should be recognized in any general scheme for appraising soil maps of the world.

Important soil properties and attributes for use

It is self-evident that one must know what soil properties are important for a given use before he can intelligently appraise the potential of soil for that use. It is not so obvious that individual soil properties must be considered in combination and that the interactions among them commonly determine their relevance. Coarse texture, for example, carries one set of implications for use of soils having ustic moisture and different implications for use of udic or aquic soils. Soil acidity has different implications for management depending on cation exchange properties. In an on-site appraisal, a soil scientist would mentally integrate the implications of sets of properties, including their interactions. He would, furthermore, arrive at judgments of critical soil attributes from clues provided by individual properties in combination. A scheme for appraising the utility of soil maps must provide mechanisms for judging the effects of combinations of soil properties as sets that collectively determine soil potential.

Degree of soil limitations

A soil scientist commonly approaches an on-site appraisal of the potential of soil resources with a concept of a near-ideal set of properties for a pre-determined use or uses. He commonly searches for soil limitations that would detract from the maximum potential of an ideal soil in the environment. Some limiting soil properties prohibit certain uses absolutely; very steep slope would be such a property for mechanized farming. Some limit soil performance though they would not prohibit the use. Some of these can be corrected feasibly, and others cannot. The point is that, for a given use, sets of soil properties and their interactions may range from absolutely prohibiting to nearly ideal. The vast majority limit soil performance to varying degrees and may be corrected with varying degrees of difficulty. A final judgment of soil potential should reflect the impact of these variable degrees of soil limitations and the feasibility of correcting them in the physical environment of the area. A general scheme for appraising the utility of soil maps should provide a mechanism for assessing the adequacy of the information provided for making such judgments.

Geographic distribution of critical soil conditions

It is not enough to appraise the soil in one place, for the soil of land areas large enough for most uses is not uniform. In an on-site appraisal, a soil scientist would determine not only which soil limitations vary and how much but also the geographic pattern of different degrees of limitations. For some uses, the geographic pattern is more critical than the limitations at one place or the amount of an area affected. Five percent wet soil in a field otherwise suited to mechanized farming, for example, may be no more than a nuisance if it is all in one place. It can control cultural operations and timeliness of work if it is distributed in small pieces throughout the field. A scheme for appraising the utility of soil maps should include provision for assessing the adequacy of information about soil patterns within delineations as well as among them.

II B. APPRAISING SOIL MAPS

The utility of soil maps is approached here in terms of the degree to which they provide the information one needs to appraise the soil itself. The point has already been made that they provide only part of the information one could obtain from on-site investigation. This section is organized according to the five items of the section on appraising the soil itself. The last four items involve attributes of soil maps; the first item is independent of soil maps but must be a factor in appraisal of their utility.

Land use for which soil maps are to be appraised

Objectives differ in both the level of generalization and kinds of land use for which soil maps are appraised. Both affect the soil information needed for meaningful interpretation. The number of specific uses is so great that it is not feasible to provide guidelines to appraise soil maps for them all. Table 2 is suggested as a first approximation of the kinds of land use groups for which guidelines might be provided. It should be understood, however, that soil maps also need to be appraised for very specific uses.

Level of detail or generalization

This subject, as stated, could include both (1) the cartographic detail of the map itself and (2) the categorical (classification) detail of the map legend. The first concerns the

Table 2. A tentative scheme for identifying elements of soil use and management at different levels of intensity.

Broad Land Use Classes	Cultural Systems within Use Classes	Broad Groups of Plants in Cultural Systems	Specific Plants	Management Systems
1. Cropping	1.1 Shifting cultivation	1.11 Annual crops	Maize, etc.	
	1.2 Wet culture	1.21 Annual crops	Rice, etc.	
	1.3 Dryland culture	1.31 Annual crops	Maize, etc.	
		1.32 Perennial crops	Cacao, etc.	
	1.4 Irrigated dryland crops	1.41 Annual crops	Cotton, etc.	
		1.42 Perennial crops	Sugar cane	
2. Grazing	2.1 Dryland	2.11 Native species		
		2.12 Introduced species		
	2.2 Irrigated	2.21 Introduced species		
3. Forestry	3.1 Dryland	3.11 Native species		
		3.12 Introduced species		

It is not suggested that guidelines should be developed for appraising soil maps for all of these uses.

number and size of delineations in relation to land area and is discussed in this section. The second concerns the definition of map units in relation to the range of sets of soil properties in the area. It is more appropriately discussed in the next section on "Composition of Map Units."

Cartographic detail is a function of scale on most soil maps. Some soil maps, however, are at scales much larger than would be necessary to present the map units legibly. Others crowd so many boundaries and symbols on a small piece of paper that the map is not legible. A measure of cartographic detail that is independent of the scale actually used is needed. It is suggested that the minimum scale at which the map data could be presented legibly would be a potential index of cartographic detail.

Such a "legibility scale" would have deficiencies as a measure of cartographic detail. The delineations of some soil maps may be mainly large, but a few may be so small that they would not be legible if the scale were reduced. The legibility scale of such maps might be based on legibility if the small delineations were identified by "spot" symbols. Spot symbols, too, detract from legibility, so their numbers should not be great.

Another potential deficiency of a legibility scale as a measure of cartographic detail would be the unknown relationship between detail of the map and complexity of the soil pattern in the field. The soil pattern of some areas is very complex; in other areas it is very simple. Degrees of cartographic detail, in one sense, could reflect the relationships between map unit patterns and soil patterns in the field. As the soil pattern in nature commonly cannot be determined with certainty from soil maps alone, one is probably forced to depend mainly on map definitions in relation to land areas as an index of cartographic detail.

An experienced soil scientist could possibly judge legibility scale by inspection as accurately as may be justified, considering other unmeasured factors related to its significance. It is by no means certain that two experienced soil scientists would judge

it the same. Persons who are not experienced field soil scientists or cartographers need less subjective ways to appraise cartographic detail. Soil scientists need objective criteria of exactly what "legibility scale" may be. Relationships between legibility scales and measurable map attributes can be established. Such attributes as number of delineations per unit land area, average or median size of delineation in land-area dimensions, and counts of transect intercepts with soil boundaries can be measured and related to minimum scales of maps that experts agree would provide legibility. Guidelines for scale in relation to legibility may have been established by cartographers for soil or other kinds of maps. If this has been done, it would be desirable to use established cartographic conventions.

The use of map scale as a criterion of soil map utility would be greatly facilitated by a set of standard scale classes. In many respects, it would be desirable to use the ranges of scales identified as criteria for "orders" of soil surveys in the United States. These ranges, however, were conceived as guides for future soil surveys—not as criteria for classifying existing maps. Consequently, map scale is tied to kinds of map units and levels of taxonomic soil classes. The relationships defined do not fit those of many existing maps throughout the world. Also, the ranges of map scales defined for the five orders of soil surveys overlap and would be difficult to apply objectively for soil map appraisal.

For the reasons given above, a classification of map scales is suggested here, as follows:

Class A—Greater than 1:13,000
Class B—1:13,000 to 1:26,000
Class C—1:26,000 to 1:130,000
Class D—1:130,000 to 1:650,000
Class E—Less than 1:650,000

Class limits are suggested to bracket the map scales most commonly used. Unusual fractions are suggested as class limits to avoid problems when map scales happen to coincide with class limits.

Class A would include only maps of those highly detailed soil surveys which are made for special purposes. In English units, maps at 8 inches to 1 mile would be included. Class B includes the common scales of so-called detailed surveys (order 2) in humid parts of the United States—1:15,840; 1:20,000; 1:24,000; and 1:25,000. Class C includes many of the older soil survey maps of the United States, which were mainly at scales of 1:31,680, 1:63,360, and 1:63,500. Some soil maps of order 2 published at scales of Class B would be Class C at a legibility scale. Many of the "general" soil maps included in recent published surveys of the United States would also be included, although some of these would be Class D on a legibility scale. Note that maps at 1:125,000 and, in English units, at 2 miles to 1 inch would be near the lower limit of class C.

Class D includes many soil maps designed to give perspective of soil resources of large areas. The most common scales are 1:250,000 and 1:500,000. In English units, Class D would exclude scales of 2 miles to 1 inch at the larger limit and include scales of 8 miles to 1 inch at the smaller limit. Class E includes many schematic and compiled maps, as well as those made by exploratory methods with field observations at very wide intervals. The most common scales are probably 1:750,000 and 1:1,000,000 but the very small-scale maps of continents and other large areas at scales of 1:5,000,000 and smaller would be included.

Composition of map units

This subject relates to the headings "Important Soil Properties and Attributes for Use" and "Geographic Distribution of Critical Soil Conditions" in section II A of this paper. It refers to the information provided by the legend and related descriptive material about sets of soil properties and their geographic distribution within the boundaries of soil maps. It includes two interrelated elements: (1) the kinds of map units identified in map legends and (2) the definition of those units in terms of kinds of soil they contain. The two are considered individually here.

Kinds of map units. The two distinctive kinds of map units are (1) those that can be identified as single taxa without distorting concepts of homogeneity and (2) those that must be identified as two or more intermingled taxa to create a realistic picture of heterogeneity. The first has recently been called a *consociation*. The second has long been called an *association* or *complex,* depending on scale. The first implies that the unit can be interpreted as a single kind of soil confined to specific places by boundaries on the map. The second implies that the unit must be interpreted in terms of a mixture of at least two, commonly contrasting, kinds of soil. The first signifies that the map shows by its boundaries the important geographic variability of soils at some level of categorical detail. The second signifies that the map boundaries identify only part of the important geographic variation. The remaining part is within soil boundaries, but one does not know precisely where. This is an important difference for interpreting soil maps.

Other kinds of map units are used. An *undifferentiated group,* as used in the United States, includes two or more kinds of consociations which have been combined because they would be interpreted similarly for most purposes. They differ in their taxonomic classes. Areas of the two may or may not be contiguous, but they are not so intimately intermingled they could not have been delineated separately at the map scale. Undifferentiated groups can be treated as consociations for purposes of interpretation. They can be appraised in that context for utility of soil maps. Undifferentiated groups of soil associations are also used on some maps. As they must be similar for interpretation, they can be appraised like single associations for map utility.

A fifth kind of map unit, recently called an *unassociated group* includes areas of two or more unlike kinds of soil at some level of categorical generalization. The soils identified within one unit are unlike not only in taxonomy but also in use potentials. Such units may be used deliberately in exploratory surveys or for compiled maps when the limited information available provides evidence that two or more contrasting kinds of soil may exist in identifiable areas, but the evidence is not adequate to decide which ones. Individual delineations may be one or the other, or both. These kinds of map units are more likely to be found or suspected as inadvertent errors due to poorly conceived legends, incompetent mappers, or both. They are likely to represent only part of the legend, but their presence should be identified.

Kinds of soil. The second element in composition of map units is the kinds of soil they contain. Kind in this context does not imply taxa in some taxonomy but sets of soil properties, classified or unclassified. Map unit definitions derive from connotations of the names of the taxa that identify them, phase or other qualifying terms used to modify the taxonomic name, and descriptive material in the text.

Most delineations on soil maps are identified by names of taxa in some system of soil classification. The name itself implies a set of soil properties, which is defined explicitly in some systems and implied in only very general terms in others. The name of a taxon at a low taxonomic level implies a relatively narrow range of a set of many

soil properties. A soil family in the U.S. system is an example. A name at a higher taxonomic level, such as great groups of the U.S., implies that a smaller number of properties range within narrow limits, selected properties range within broader limits, or both. At the soil family level in the U.S. system, for example, soil texture, mineralogy, and attributes related to moisture regime range within narrow limits. At the great group level, attributes related to moisture regime range more widely but are defined. Soil texture and mineralogy, however, are undefined and, therefore, must be presumed to range as widely as is possible within whatever limits may be imposed by genetic requirements for formation of features diagnostic at the great group level. Both texture and mineralogy of great groups may range far beyond limits critical for appraising soil potential for some uses, and their character in a specific map unit defined as a great group is unknown from the taxonomic name alone.

The taxonomic level of soil names in a map legend implies a great deal about the level of generalization at which one can make valid predictions about the utility of maps. It does not, however, identify which soil attributes critical for land use are defined and which are undefined. This commonly varies among taxa of the higher categories of a given system and even more widely among the taxonomic systems used throughout the world.

Phases are very important features of legends. They are used to increase critical information about attributes of soils in map units defined at any taxonomic level. They increase the prediction value of the map immensely. It should be noted emphatically that map units identified as appropriate phases of taxa of high categories may be more useful for some interpretations than others identified only as taxa of categories low in the same system. Even the term *steep soils,* which is effectively a phase of the entire population of soils, defines a single attribute that may control land use.

Phases are defined in the United States as subdivisions of single taxa. Critical attributes of entire areas of soil associations are also designated in map unit names for some maps. Though these are not phases by definition, they serve the same purpose for mixtures of taxa that phases serve for single taxa. The term *qualified units* has been proposed for them.

A text should accompany every soil map to provide important information that cannot be inferred from the map and legend. It is as important to appraise the information in the text as to determine that provided by the map and the legend.

It may be useful at this point to recapitulate the elements of legends and texts that determine how much or how little is recorded about the composition of map units:

1. Kinds of map units. (a) Consociations and undifferentiated groups of consociations; (b) Associations, complexes, and undifferentiated groups of associations (complexes); (c) Unassociated groups. These imply by their names whether or not map units can be interpreted as: (a) one kind of soil, (b) geographic mixtures of two or more contrasting kinds of soil, or (c) areas in which either of two or more contrasting kinds of soil may dominate.

2. Taxonomic level of taxa used to identify map units. This implies a level of generalization to which interpretations should be adjusted. It does not imply which attributes of soils are defined.

3. Definitions of taxa used to identify map units. These should identify sets of soil properties from which one can infer the kinds and ranges of some of the soil attributes that control use potentials within map units. These definitions may be understood from the name of the taxon or may be stated in a text.

*4. **Phase and other qualifying criteria.*** These should add to the list of soil attributes that control use potentials.

*5. **Soil properties and attributes described in the text.*** The text of well-conceived and well-executed soil surveys gives critical information about map units not implied by the names of taxa or phase criteria and adds to the list of attributes that control use potentials.

Beyond these elements, one needs to consider the extent to which map unit names and descriptions accurately represent the character of delineations. It should be noted that *inclusions* comprise a large part of most map units. They may or may not be identified. If inclusions are *similar soils,* i.e. have potentials for use comparable to those of identified taxa, they detract little from interpretations based on named taxa and phases. If they are *dissimilar,* they should be elements in appraisal of map utility. A major problem must be faced when inclusions are not mentioned. The omission detracts greatly from certainty of map appraisal. Many soil maps identify map units in terms of single taxa without reference to associated soils or inclusions. These should be suspect.

Degree of soil limitations

The utility of a soil map depends heavily on the extent to which it permits one to identify the limiting attributes for which a soil scientist would search in an on-site investigation and to segregate them geographically. Some limiting attributes are direct consequences of single soil properties (e.g. steep slope) that are recorded in definitions of map units. Others (e.g. periodic wetness) are inferred from recorded evidence. They may be identified in taxonomic names or in soil descriptions for a given map, or they may have to be inferred from information that is given about the soil.

For an appraisal of the utility of soil maps, this individual sees no good alternative to a system that includes determination of the extent to which the map and associated documents identify the kind and degree of soil limitations for use. This suggests need for a checklist of limiting soil conditions against which the legend and text can be appraised in terms of the completeness of information they provide. Following is a first approximation of a list of soil attributes that are important for a broad range of uses.

A. Soil moisture relationships
   1. Soil moisture regimes
      a. Intergrades among them
   2. Available moisture capacity (In relation to rooting depth)
B. Soil temperature relationships
   1. Soil temperature regimes
      a. Intergrades among them
C. Chemical properties
   1. Colloidal behavior
      a. Clay mineralogy
      b. Cation exchange capacity
   2. Soil fertility
      a. Nutrient supply (organic matter, weatherable minerals)
      b. Nutrient fixation
   3. Soil acidity
   4. Soil salinity and sodicity

D. Physical properties
   1. Related to rooting
      a. Aeration
      b. Physical obstruction (depth to pans, bedrock)
   2. Permeability
   3. Tilth (texture, consistence)
   4. Obstructions to culture
      a. Stoniness
      b. Rock outcrop
      c. Slope

It should be important to determine which of the items in this list, as well as others, are revealed by the definitions of taxa listed in the legend, phase criteria used, and information in the text. Some may be inferred from general information about the area as a whole — such as inferences about soil moisture and temperature regimes from description of the climate. Some of the items listed may be inferred though not mentioned specifically—absence of reference to salinity in a humid region is likely to suggest that salinity is not a problem.

It should also be possible to rate items of the list according to the degree of specificity or level of generalization with which they can be appraised for map units. This would be a factor in assessing the level of generalization of land use classes for which soil maps would be useful. Possibly a 3-class system could be used:

1. Adequate for predicting management requirements.
2. Adequate for predicting crop adaptation.
3. Adequate for predicting adaptation of broad classes of land use.

To implement a scheme like this, it would probably be necessary to develop a list of the attributes which taxa at various categorical levels reveal, directly or by inference, for each of the various major taxonomies used throughout the world. This should not be an impossible task, including the level of generalization at which statements can be made about them.

Geographic distribution of critical soil conditions

The approach in the preceding section relies on appraisal of the homogeneity of "performance characteristics" within map units. There is another way to conceive of the same ideas. If one can determine how much each of the performance attributes listed varies within the area of the map, he might be able to identify three segments according to geographic characteristics of the map:

1. An identified segment stratified geographically by map unit boundaries. Slope gradient, for example, may be stratified by slope classes among different delineations by use of slope phases.
2. An identified segment confined geographically by soil boundaries but unstratified within them. The variation among taxa or phases of taxa within delineations of a soil association is an example.
3. A segment that is both unstratified and unconfined geographically. This would include all attributes which are not identified with map units in any way.

It would be very difficult, if not impossible, to develop a scheme to appraise the information provided by soil maps in this way. Nevertheless, the concept can be useful, and some elements of it should be considered in map appraisal.

The idea of total variation of soil attributes is relevant. The prediction value of a map is not decreased by failure to identify soil attributes which vary little throughout the area. If, for example, soil temperature regime varies little, failure to identify it for each map unit does not detract from homogeneity of the unit. It would be helpful, if possible, to record the total range of variation of critical attributes as a bench mark against which segregation can be appraised. Such a record would also help to identify the magnitude of variation of unclassified attributes.

The geography of variation within associations and complexes can be critical for map unit interpretation. It would be important in appraising their ability to record whether or not they are defined in terms of proportions and patterns of their constituent taxa.

Reliability of information

None of the factors discussed above is relevant if a soil map is unreliable. Few maps are totally unreliable, but many contain information that should be questioned. An appraisal of map utility should indicate an estimate of reliability. This may rate the reliability of cartography, soil identification and definition, or more commonly both.

Objective criteria of poor reliability related to human error or incompetence are difficult to establish. Some measure of ground truth is required for absolute determination. This is rarely available. There may, however, be clues on the map itself, such as identification of soils in places where they are unlikely to be found or map unit boundaries that do not conform to diagnostic landscape features. These kinds of errors may be detected by comparison with reliable topographic maps and information that may be available from other sources.

More objective criteria can be established for reliability related to techniques and methods of data gathering. Such factors as dependence on remote sensing alone, poorly designed or inadequate frequency of sampling by field methods, and poor ground control of base maps contribute to poor reliability. If the text does not describe the methods used, the fact should be noted and reliability should be questioned. Some appraisals report the predominant survey methods in lieu of a reliability rating. An example based partly on definitions of the 1951 *Soil Survey Manual* of USDA might be:

Schematic compilation
Remote sensing techniques
Exploratory field methods
Reconnaissance field methods
Detailed field methods
Methods unknown

If information is available, ratings of good, fair or poor may be applied to each method, indicating the estimated reliability within the range of precision of the method.

Geographic control of base maps

A soil map has little value if the base map does not permit geographic location of boundaries relative to accurately located ground features. The quality of the base map should be indicated, considering both the amount of ground control and its accuracy.

II C. METHODOLOGY

Sections A and B discuss factors that should be considered in a scheme to appraise the utility of soil maps. The question remains, how can one integrate all, or part, of the factors that bear on the problem to arrive at a workable and valid system? This individual began this exercise with the idea that one should be able to classify soil maps according to their attributes and then interpret the resulting classes according to utility. As the exercise developed, it became increasingly evident that a classification of maps on the basis of such characteristics as scale, kinds of map units, taxonomy of map unit identities, and other factors discussed in this paper would be extremely complex and, perhaps, unmanageable.

A mechanism should provide for appraisal of the following attributes of soil maps:

1. ***Minimum legible map scale.*** This can be interpreted in terms of the size of area for which interpretations would be appropriate, i.e. individual fields or farms, communities, states, nations—these should be defined in terms of area. The descriptive terms above are merely suggestive.
2. ***Definition of soil attributes within map units.*** This is needed to assess whether the soil map, legend, and text collectively provide enough information about the soil areas delineated to permit appraisal of their potential for use and/or management requirements.
3. ***Geography of soil variability.*** This is needed to assess how much of the total variability is within map units and, therefore, not identifiable in terms of precise geographic location.
4. ***Reliability of the map and supporting data.***
5. ***Adequacy of ground control on the base map.***
6. ***Legibility of soil information.***

It should be possible to record criteria for appraisal of all of these items in a checklist, from which a final rating for a specified use might be determined or, perhaps more meaningful, a list of deficiencies might be compiled.

Minimum legible map scale

A tentative classification of scales has been suggested in section B. These can be interpreted in terms of minimum size of delineation and size of planning units to which they might commonly be applied. A tentative interpretation follows:

Class A—Greater than 1:13,000. Suitable for appraisal of soil in delineations as small as 1/2 ha for planning units of 1 to 500 ha, such as experimental areas, truck gardens, or housing sites.

Class B—1:13,000 to 1:26,000. Suitable for appraisal of soil in delineations as small as 1/2 to 2 ha, or larger, commonly for planning units of 5 to 2500 ha, such as farms and ranches.

Class C—1:26,000 to 1:130,000. Suitable for appraisal of soil in delineations as small as 2 to 65 ha, or larger, commonly for planning units of 100 to 10,000 square kilometers, such as communities and local political units.

Class D—1:130,000 to 1:650,000. Suitable for appraisal of soil in delineations as small as 65 to 2000 ha, but mainly larger, commonly for planning units of 20,000 to 1,000,000 square kilometers, such as states and small nations.

Class E—Less than 1:650,000. Suitable for appraisal of soil in delineations as small as 50 square kilometers at the larger scales, but mainly much larger, commonly for planning units larger than 100,000 square kilometers, including large states, nations and continents.

Note that the minimum size of delineations suggested is not strictly the smallest that could be shown at the scale in all classes. Note also that the sizes of planning areas suggested are not mutually exclusive. The numbers are based on maps with which this individual is familiar and should be adjusted.

Definition of soil attributes within map units

A checklist could be developed for a list of potentially limiting attributes like that outlined in section B3. It should provide for rating each significant attribute in terms of the level of detail of the information which can be gleaned, directly or by inference, from: (a) known attributes of the area covered by the map as a whole (such as soil temperature regime), (b) connotation of named taxa, (c) phase and other qualifying criteria, and (d) information in an accompanying text. That which follows is intended only as an example of a kind of checklist which might be developed. The list is not intended to be complete, nor are the items necessarily the best. Indeed, little time was spent in serious thought about the list and none was spent reviewing soil surveys of different environments. Many items could be added. A note of caution is needed, however. It would be very easy to compile a long list of individual soil properties that would lose utility by sheer complication.

The items listed are mainly interpretations of information given in soil maps and accompanying documents. If the interpretation were not made at this point, it would have to be done in another step. The idea is to record whether or not a soil map and supporting documents provide information that would make this step feasible for a competent soil scientist.

The levels of information are meant only to suggest a type of rating system that would adapt easily to an appraisal of maps at different levels of detail of land use and soil management. The terms would need definition and examples before they could be applied consistently by different individuals. These might be needed for another level —no information at all.

Geography of soil variability

This refers to the subject discussed in section B5. Considering the lack of information about total soil variability given for most soil maps, it is probably unrealistic to attempt to rate geographic field complexity in more refinement than two classes — such as simple *vs* complex. To be most useful for appraising the utility of soil maps, such a rating should probably be assessed in terms of geographic complexity of sets of soil attributes that are critical for use and management. To be comparable from map to map, the assessment should also be in terms of soil patterns conceived at some standard scale. This should probably be at a relatively large scale, such as 1:20,000, to provide concepts of complexity that would be meaningful for a wide range of scales. Considering the dearth of information about many areas, it would also be desirable to indicate a degree of certainty for each rating.

Although ratings of field complexity would necessarily be quite subjective for many areas, some guidelines would be necessary as standards. Very tentatively, standards might be like the following:

Simple soil patterns. At a scale of 1:20,000 delineations representing areas having similar use potential would be predominantly larger than 1000 ha, and those representing areas having similar requirements for management systems of intensive uses such as crops, would be predominantly larger than 10 ha.

Complex soil patterns. At a scale of 1:20,000 delineations of similar use potential would be predominantly smaller than 1000 ha, or those of similar needs for management systems would be smaller than 10 ha, or both.

By use is meant broad use groups, such as cropping, grazing, or forestry. By management systems is meant general systems involving similar, but not necessarily identical, plants, conservation measures, fertility maintenance and the like. The quantitative values of area proposed represent, at best, crude concepts, which might or might not be realistic.

Unless the supporting documents provide specific information about field variability, judgments would have to depend mainly on inferences from other attributes of the area. Commonly, statements in the text or the character of mapping itself provides clues that the map does or does not reveal the degree of complexity that exists. Information about geology, geomorphology, and topography may permit one to predict the complexity of soil patterns. Land use patterns, if available, can be used as evidence though they are not infallible. Ratings based on inferences of this kind should be labeled as uncertain.

Variability within map units is a very important criterion of the kinds of interpretations that can be made. This subject is discussed in part in the paragraphs on "Kinds of map units" and "Geographic distribution of critical soil conditions" in section B. One suggestion for recording relevant information about this attribute follows:

1. Map units which can be evaluated as consociations __________ % of area.
   a. And are homogeneous in attributes controlling land use __________ % of area.
   b. And are homogeneous in attributes controlling management __________ % of area.
2. Map units which must be interpreted as geographic soil mixtures __________ % of area.
   a. Components differ in use potentials __________ % of area.
   b. Components differ in management requirements __________ % of area.
   c. Proportions of components defined __________ yes; __________ no.
   d. Patterns of components described __________ yes; __________ no.
   e. Are identified as associations or complexes __________ part; __________ all.

The distinction between 1 and 2 requires appraisal of more than map unit names. Some map units identified as consociations are, in fact, associations and should be evaluated under 2.

A third factor which could be evaluated uner this heading is the extent of critical soil attributes which are not identified with map units in any way in the legend or in the text. These, if they are factors in the area, must be assumed to vary within segregation by map units. (Some which are not mentioned may not be factors in the area and, therefore, are unimportant. Others may be inferred to be uniform for all areas and, therefore, are effectively known.) This would not be recorded in Table 1 as it is constructed. The item might be included in that table as "no information."

Reliability of the map and supporting data

Drawing on the list in "Reliability of information," section II B, the following could be used as a checklist:

Method of Compilation	*Reliability within Limits of Method*		
	Good	*Fair*	*Poor*
Detailed field methods, with remote sensing			
Detailed field methods, without remote sensing			
Reconnaissance field methods, with remote sensing			
Reconnaissance field methods, without remote sensing			
Exploratory field methods, with remote sensing			
Exploratory field methods, without remote sensing			
Remote sensing techniques only			
Schematic compilation			
Methods unknown			

Quality of base map

The following is a suggested checklist:

Base map adequate for the purpose __________ yes __________ no

If no is checked:

Inadequate ground control __________ yes __________ no

Inaccurate ground control __________ yes __________ no

Culture illegible __________ yes __________ no

Culture obscures soil information __________ yes __________ no

Legibility of soil information
The following are items that may be relevant:

Legibility is adequate for the purpose:	______ yes	______ no
If no is checked:		
Too much detail for scale	______ yes	______ no
Symbols illegible	______ yes	______ no
Color pattern detracts	______ yes	______ no
Overprint patterns detract	______ yes	______ no

The Cost-Benefit Relationships of Soil Surveys

Philip Beckett

It is not always clear why particular soil surveys were carried out. Nevertheless, when soil surveys are justified publicly it is on their practical value, so they should be assessed on their practical value too, that is on how far the existence of a soil map and its supporting documentation has enabled the members of a community to conduct their activities more economically, or to do more things for the same investment, than they could have done without it.

The paymaster of a survey or the users of its results are not necessarily interested in the cost-benefit ratio as such. Usually they are concerned to know the likely minimum cost of achieving a given benefit, or the likely maximum benefit from a given investment, and in either case they want the answer before the survey is commenced, or at least by the end of the reconnaissance stage that should precede mapping, in order to make the crucial decision—"should we do this survey at all, and if so how?"

Obviously the cost-benefit ratio has two components, of which the former is more easily estimated, and I shall discuss them separately.

COSTS

The cost of information increases with its precision and specificity, in soil sciences as anywhere else. Consider one survey area of average complexity, in which the whole range of soil variability in the soil mantle of the survey area can be divided into: 5 soil sub-groups, or 15 soil families, or 40 soil series, or 130 soil phases. We need not here discuss the nature of the criteria on which these divisions are made, except to note that very few of them are directly relevant to current or future land use in the area, and that it is assumed that the classes at each level show a narrower range (or greater "uniformity") of some or all of the relevant soil properties than the classes in the level above. Ideally, all the classes at each level will show approximately equal breadth of concept and equal uniformity in their relevant or useful properties, but this may be very difficult to achieve. Whatever their level of subdivision the soil classes adopted to define the mapped soil units become the basic units of information: the survey cannot specify the soil properties at any place more precisely than they can be specified for the classes adopted for the survey. Since the precision of the information required increases with the intensity of land use, the level of sub-division depends on this too (Figure 1).

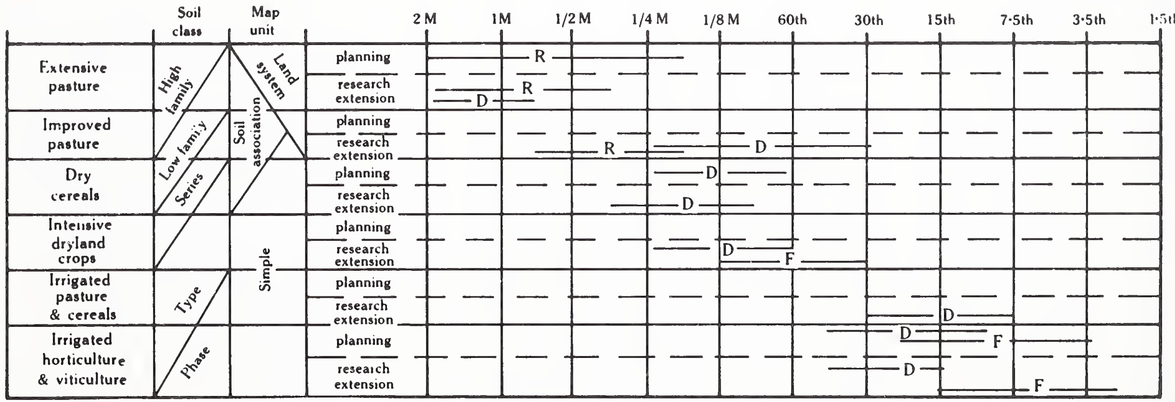


Figure 1. The level of soil classification is adjusted to the intensity of land use and to the level of decision (R, regional; D, district; F, farm): other interrelations follow from this. (Data from a wide range of Australian soil maps: Beckett and Bie, 1978; reprinted by permission of CSIRO.)

There is little point in defining, and talking about, narrower soil classes than can be represented on the soil map, and the "purity" of the mapped units on a soil map should not vary with the breadth of the classes mapped (or the point of adjusting class breadth to land use will be defeated), so the average distance between the soil boundaries to be mapped must decrease as the classes are defined more narrowly. The average density of boundary on a published soil map should be relatively independent of its scale and purpose (Figure 2), so the publication scale of the soil map should be adjusted to

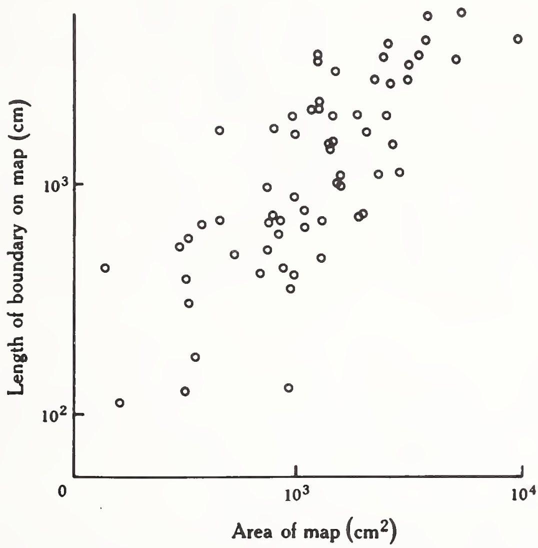


Figure 2. There is an optimum density of soil boundary on a soil map, not greatly affected by its scale or purpose. (Beckett and Bie, 1978; reprinted by permission of CSIRO.)

average boundary density (Figure 3). Therefore, soil class and publication scale will also be related (Figure 4). The scale of the base map used in the survey ("field scale") should be about twice publication scale (Table 1). More often than not the constituent series of a soil family are separated by series from other families, so the grouping of series into families, or other higher groupings, may not reduce the length of boundary to be mapped, and at scales of 1:30,000 or smaller the surveyor has to define compound units (Figures 1 and 5, and see Bie and Beckett, 1971a). This makes cost-benefit discussions more complicated, but since it does not alter their basic principles the rest of this paper discusses only large- to medium-scale maps of simple (single-class) mapping units.

The closer the soil boundaries to be mapped, the greater the density of observations that will be needed to locate them, and the greater the effort required per unit area surveyed (Table 2). Also the proportional contribution of air photograph interpretation

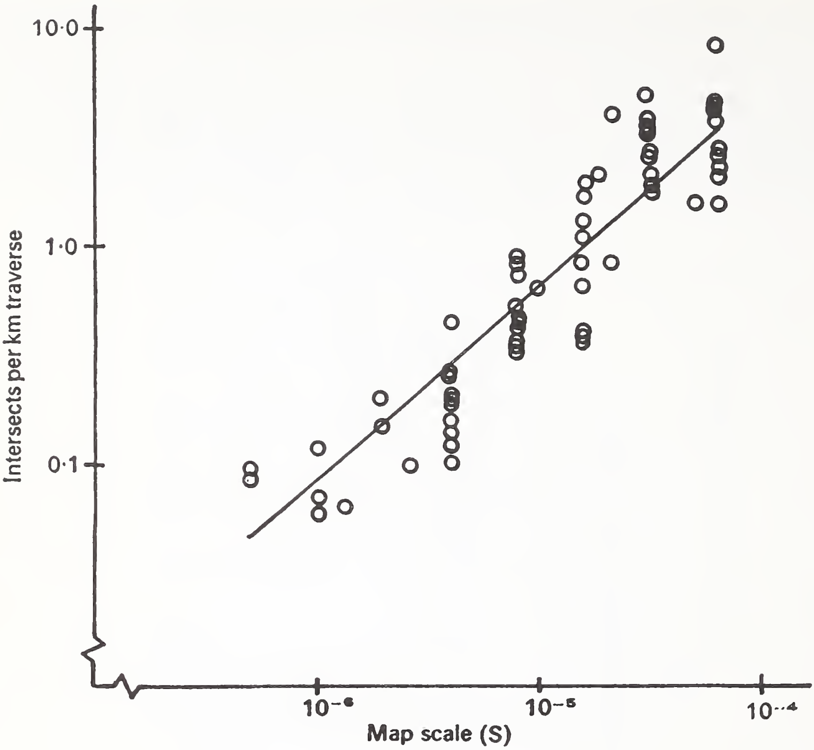


Figure 3. Map scale is/should be adjusted to the frequency of the soil boundaries to be mapped, in this case estimated as the average number of boundaries crossed per unit length of random linear traverse from a wide range of Australian soil maps (Bie and Beckett, 1971a).

decreases with map scale (Figures 7 and 8). So the density of soil examinations (Table 3), and the cost of soil survey in effort (Table 4 and Figure 7) or money (Figure 6) increases with map scale. Cost or effort vary considerably with landscape, even within one region (Figure 9).

Nevertheless, the precision achieved is not necessarily related to the effort applied. Figure 10 averages the fraction (in the range 0–1) of the total variance of topsoil clay content, organic matter, and available magnesium that is successfully described by a range of soil maps of increasing scale, in each of the three areas of Figure 9. (Burrough et al., 1971 give further information). Clearly by these criteria, and in this area, there is little benefit from mapping soil series by conventional free survey or grid survey at scales greater than 1:25–1:20,000. To achieve much increase in precision beyond this scale it will be necessary to produce single-property maps by grid survey.

This is universal: in every landscape there is a certain intensity of survey effort, beyond which the cost of further precision increases sharply and in proportion to the degree of precision already achieved. This is the Law of Diminishing Returns.

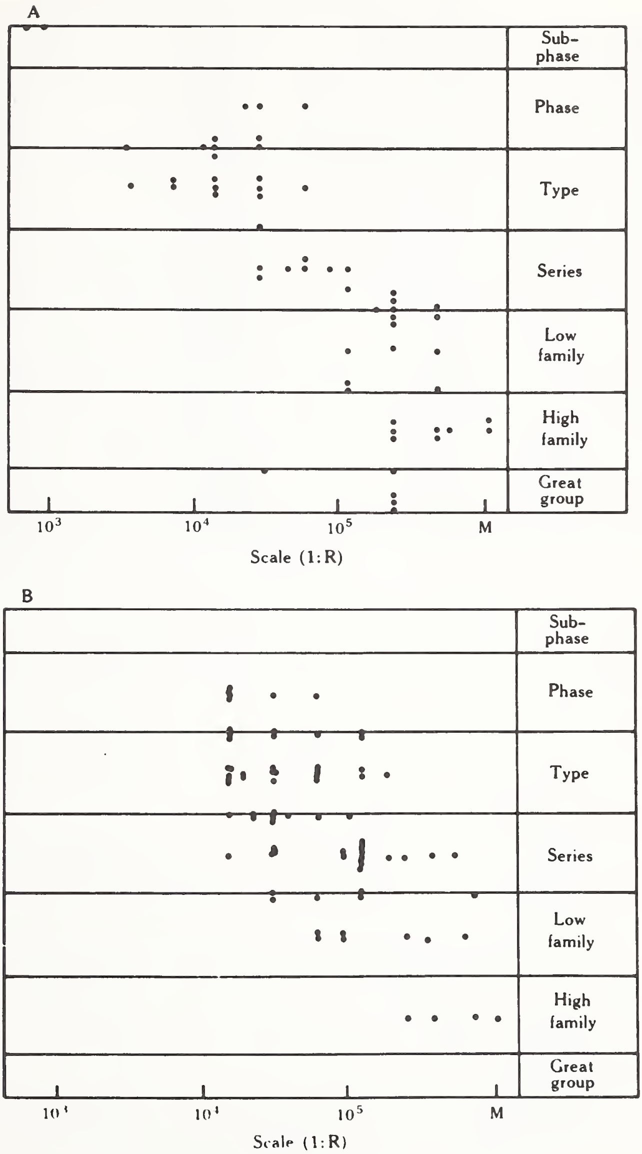


Figure 4. Map scale and the level of soil classification are interrelated. (Sets of data from (A) Federal and (B) State soil surveys in Australia: Beckett and Bie, 1978; reprinted by permission of CSIRO.)

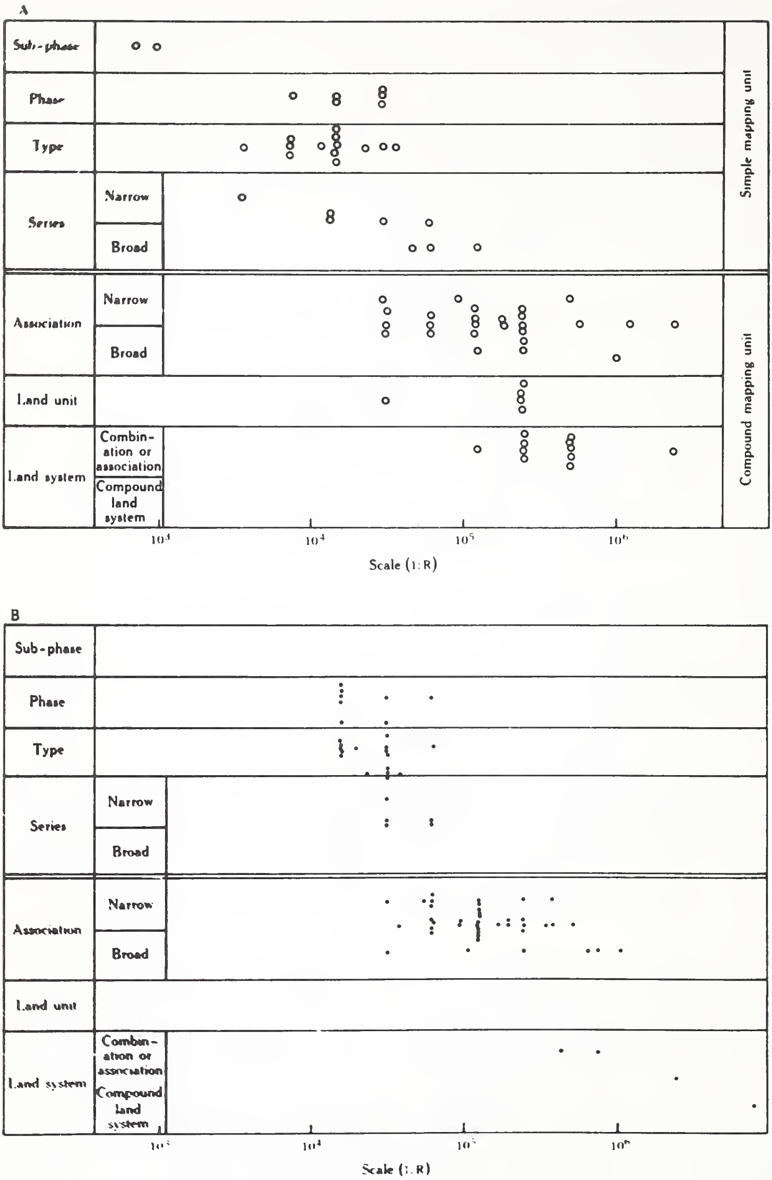
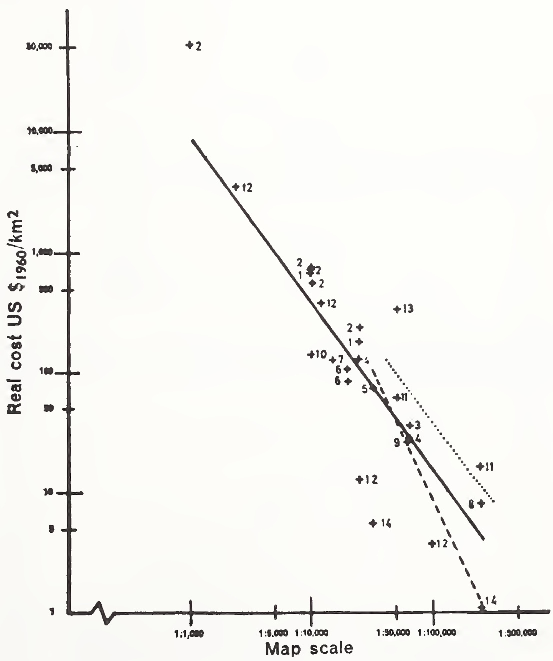


Figure 5. Map scale and the complexity of the soil mapping units are interrelated (as Figure 4). Reprinted by permission of CSIRO.

Table 1. The relationship of field scale to publication scale.

Publication scale	Field scale	Reduction factor	Country
1:2,534	1:2,534	1.00	Eire
1:10,000	1:10,000	1.00	Iraq
1:10,000	1:6,000	1.67	Lesotho
1:20,000	1:15,840	1.26	U.S.A.
1:20,000	1:5,000	4.00	Belgium
1:20,000	1:10,000	2.00	Tanzania
1:20,000	1:20,000	1.00	Fiji
1:20,000	1:6,000	3:33	Lesotho
1:25,000	1:20,000	1.25	Thailand
1:37,500	1:15,000	2.50	Thailand
1:50,000	1:50,000	1.00	Thailand
1:50,000	1:40,000	1.25	Nigeria
1:50,000	1:10,000	5.00	Belgium
1:50,000	1:20,000	2.50	Spain
1:50,000	1:25,000	2.00	Netherlands
1:50,000	1:25,000	2.00	Portugal
1:63,360	1:25,344	2.50	Scotland
1:100,000	1:60,000	1.67	Brunei
1:300,000	1:100,000	3.00	Belgium
1:500,000	1:200,000	2.50	Hungary

(S. Western, 1979)



(The broken lines are from Veenenbos (1957) graphs)

Figure 6. The cost of soil survey increases with map scale: 1–2 Netherlands, 3–4 U.K., 5–6 U.S.A., 7 Australia, 8 New Guinea, 9 Eire, 10 Rhodesia, 11 Rwanda, 12 Sarawak, 13 Iraq, 14 New Zealand. (Bie and Beckett, 1970); reprinted by permission of the Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, Slough SL2 3BN, England.)

Table. 2. Rate of survey in hot climates.

Aim	auger-hole depth (cm)	Intensity: distance between (m)	No. of sites man-day[a]
Irrigation,		100	6
	500	200	5.5
Drainage,		500	4.5
		1000	4
general		5000	3.5
		100	10
engineering	300	200	9
		500	7
		1000	6
		5000	4.5
Forestry		100	14.5
		200	12
and	200	500	9
		1000	7
tree crops		5000	5.5
Field crops		100	18
		200	14.5
and	150	500	10
		1000	8
Pastures			
Exploratory survey	150	5000	5.5
General		100	18
		200	14.5
purpose	100	500	10
		1000	8
survey		5000	6

(after S. Western, 1979)

[a]Assuming one field-day comprises 7 hours, of which 1 hour is spent in travelling to and from the area of survey, leaving 6 hours for actual survey.

Table 3. Density of ground observations in relation to map scale.

Scale of published map	No. obs/ha	No. obs/cm² of map	Country
1:1000 to 1:5000	5	.05–1.3	W. Germany
1:2500	1.2	.08	Thailand
1:5000	16		Netherlands
1:10,000	1–8	1–8	Netherlands
	0.2–4	.2–4	Hungary
	0.05	.05	Iraq
	0.06	.06	Lesotho
1:20,000	0.07	.3	Tanzania
	0.04	.2	Fiji
	0.07	.3	Lesotho
	2	8	Belgium
1:25,000	0.1	.6	Thailand
	0.7–1	4.4–6.3	Netherlands
1:37,500	0.01	.15	Thailand
1:50,000	0.01	.3	Thailand
	0.03	.8	Nigeria
	0.20	5	Netherlands
1:100,000	0.003	.3	Brunei

(adapted from Western, 1979)

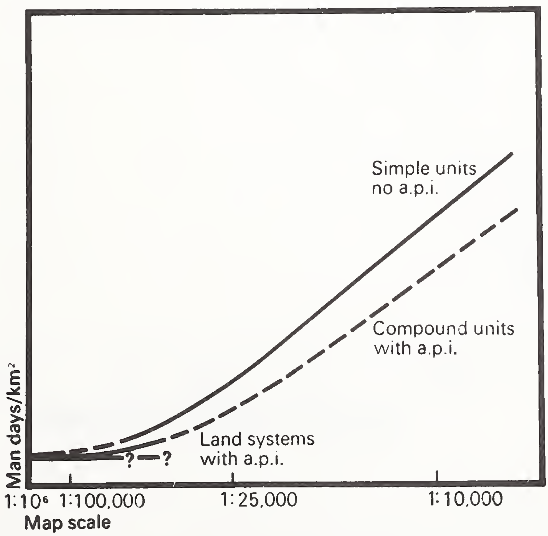


Figure 7. The total professional field effort on 66 soil and land system surveys in Australia with and without air photo interpretation. (Beckett, 1971; reprinted by permission.)

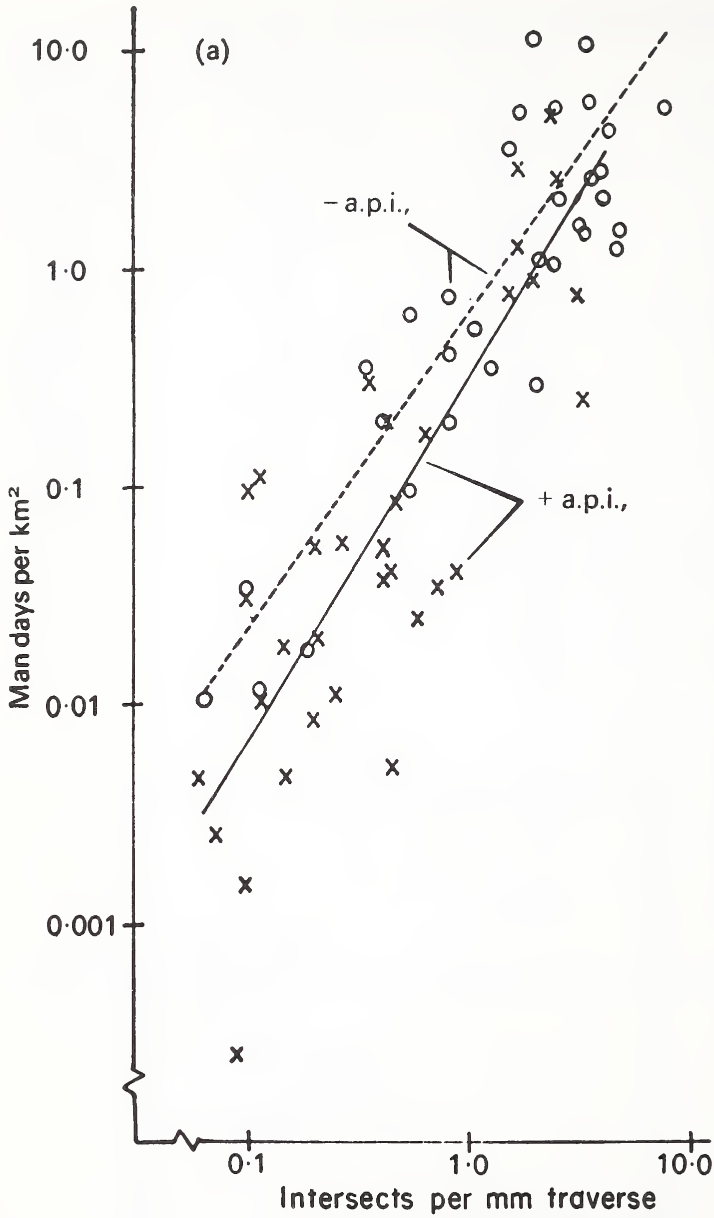


Figure 8. Survey effort increases with the density of boundaries to be mapped, and may be reduced with air photographs, but the contribution of air photography decreases as map scale increases. (Bie and Beckett, 1971 a).

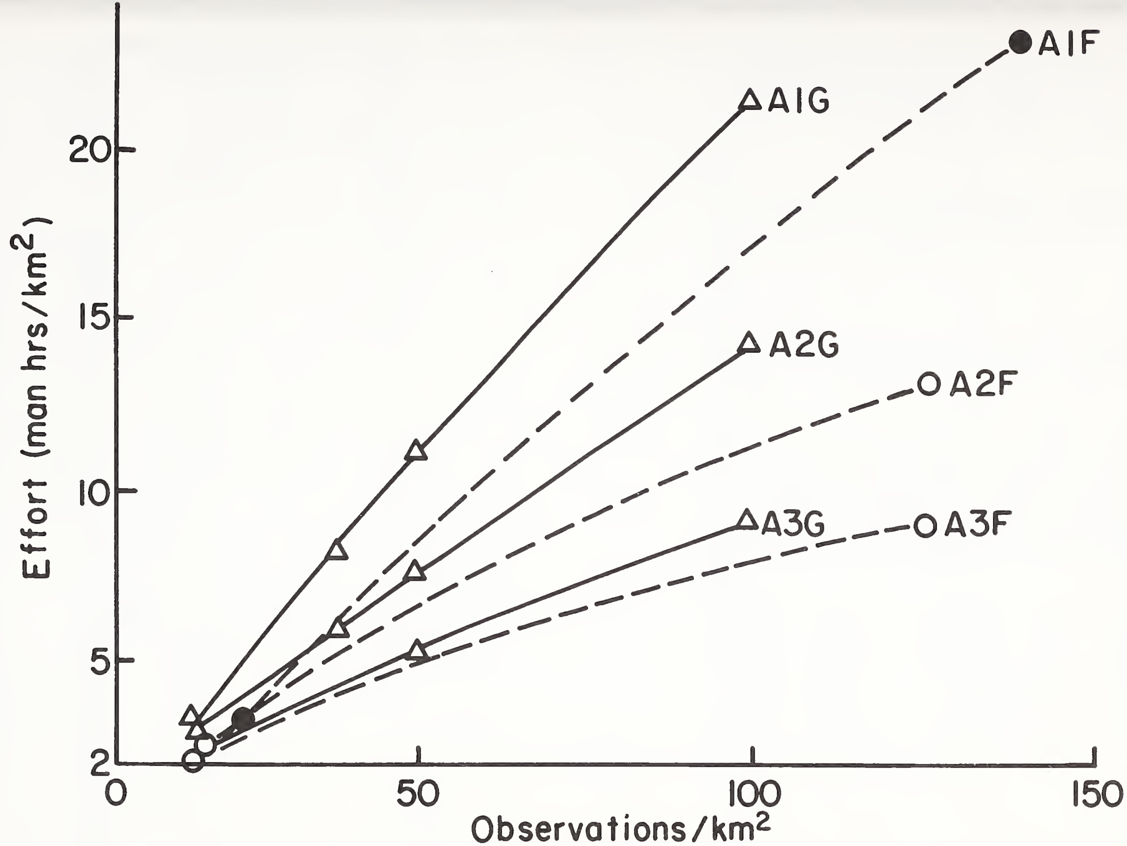


Figure 9. The total effort required to map soil series in three areas A_1, A_2, A_3) by free survey (F) and grid survey (G) increases with observation density (after Burrough et al., 1971; reprinted by permission of Oxford Univ. Press.)

Table 4. Cost of consultant survey proposals.

Publication scale		Country	Year	Cost (£/ha)	Extent (ha)
	Exploratory	Yemen (P)	1976	0.002	19.6 x 10^6
		Thailand (I)	1973	0.002	5 x 10^6
1:250,000		Brazil (U)	1973	0.001	24.3 x 10^6
	Low intensity	Indonesia (I)	1973	>0.13	25 000
1:100,000		Zambia (U)	1967	0.53	240 000
	Medium intensity	Thailand (I)	1971	0.37	133 000
		Ivory Coast (I)	1970	0.41	109 000
		Fiji (I)	1968	>0.41	20 000
		Ethiopia (I)	1973	>0.89	27 000
1:25,000		Nigeria (I)	1972	0.93	37 000
	High intensity	Somalia (P)	1975	5.23	15 000
1:10,000		Greece (I)	1972	6.64	1000
	Very high intensity	Brunei (P)	1975	91.46	12 000

(I) proposal implemented; (P) proposal pending; (U) proposal unsuccessful. (Modified from S. Western, 1979)

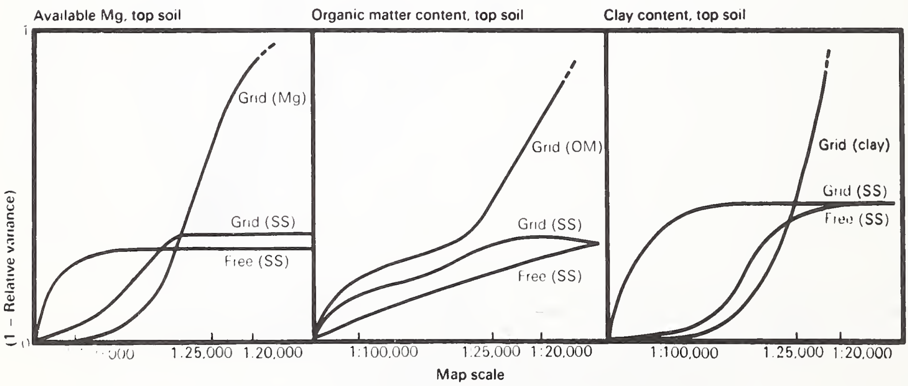


Figure 10. Increasing the density of soil observations (for free or grid survey) and thereby increasing map scale, increases the uniformity of topsoil, Clay, Magnesium and Organic matter, within the series (SS) or between isolines on single property maps: uniformity is expressed as

$$1 - \text{Relative Variance (RV)} = 1 - \frac{\text{variance of property within mapping units}}{\text{total variance of property within survey area}}$$

Much of the above can be approximately assessed on the reconnaissance that precedes a soil survey. We have explored (Beckett, 1967; Beckett and Bie, 1975) the use of auto-correlation plots for predicting the uniformity of the mapping units that would be achieved at different boundary densities and map scales.

BENEFITS

It is more difficult to assess the benefits from a soil survey. There are plenty of anecdotal claims that this or that school, hospital or housing project incurred unnecessary expense because it was built on a flood plain or peat bog that a soil map would have recorded, or conversely that money was saved because they were not built on a peat bog, etc. that a soil map did record. This kind of evidence is highly selective and difficult to evaluate: how many hospitals, etc. were built on suitable sites without the aid of a soil map? How many mapped peat bogs, etc. lay nowhere near a potential building site? How many hospitals, etc. were built on peat bogs, etc. that the soil map had failed to map? Or how many were moved from the site of first choice because the map had hinted at a peat bog, etc. that was not there? If such data are to be used they must be collected in a systematic and unbiased manner: otherwise they are better left for exercises in public relations.

The datum or starting point against which to evaluate the benefits from possessing a soil map is not a state of zero knowledge, but that amount of local knowledge already possessed by the intelligent layman, of which every community possesses at least a few.

We may assume that the useful life of a soil survey is 25 years. On the one hand most contracted single-purpose soil surveys are part of projects which economic analysts usually assume to have a life of 40 years—which is in fact the average man's concept of eternity. On the other hand economic changes and technological advances may require other soil differentiations than those offered by the survey—it is more usual that the land capability classification becomes obsolete than the soil classification or map legend. Vink (1963) suggested that where land use and soil survey are intensive a survey may be useful for only 5–10 years, but for up to 20 years in areas of more extensive land use. Bie (1972) noted that intensive surveys of some Australian irrigation areas were still in demand after 35 years. Klingebiel's (1966) 25 years seems to be a sound average. The following discussion on benefit analysis assumes a useful life of one year only, because this makes it easier to present. The form of the analysis is not affected, and its results may be scaled up by a factor of 25-fold, with whatever sophistications of compound interest or discounted cash flow the reader likes to apply.

Before proceeding to examine the soil survey itself we must ascertain what the farmer (or the land user) is trying to do—which of the economic parameters of his situation is he trying to optimize? Figure 11 illustrated diagrammatically how the value of the yield or output per unit area from one land use (one crop, a defined rotation of crops, a housing development, etc.) in two fields depends on the values of all variable inputs per unit area (seed, fertilizer, hire of plant, managerial skill). It is not necessary to subsume all inputs into one, as here. A computer can perfectly well visualize and handle an n-dimensional response surface—of one yield and (n - 1) inputs. I have simplified this only to be able to represent it in two dimensions. In n dimensions the land user can choose for example between more managerial skill (i.e. thinking harder)

or more fertilizer, and between more water (i.e. irrigation) or lower seed rate and higher phosphates, within each value of total input, but the basic manipulations of a complete response surface are the same as the following manipulations of a response curve. The solid lines are basic response curves typical of a poorly developed area (A) and a highly developed area (B). In effect the farmer, etc. in area B already starts some way up curve A because of the residual effects of earlier inputs. The line (--------) at gradient 45° comprises all situations where the land user breaks even (output = input), and line (-.-.-.-.) represents the situation where input = output $(1 + \alpha)$, where α is a predetermined profit level. The landowner chooses his level of input to maximize profit (a), or the percentage return on his variable input (gradient b), or yield for predetermined profit (c), or yield without loss (d - this is more appropriate to governments than individuals). These four criteria are not equally wise, nor are they equally applicable to all situations. Social factors may limit the available quantities of one or more important inputs, and the traditional human factors of sloth or envy may limit an individual's input or the output he dares to be seen achieving. Also the response curves can be modified to include the effects of subsidies on a per area or per unit yield basis. There are various other criteria of success. In the following discussion it is assumed that the farmer wishes to optimize his profit (a on figure 11). Whether he knows them explicitly as a result of research and extension work, or learns them implicitly from local tradition based on the operation of natural selection against those farmers who consistently choose non-viable options, he is aware of a set of such curves, one for each potential land use.

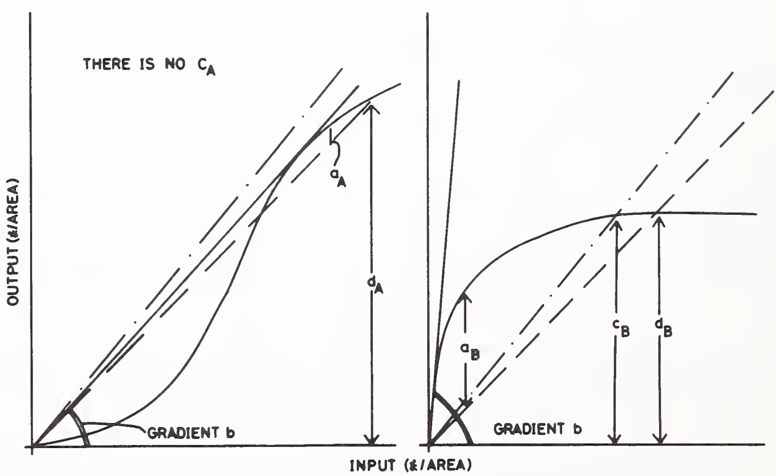


Figure 11. Yield or output (———) from poorly developed (A) and ā highly developed (B) area increases with total variable input: ----- = line of Output = Input; -.-.-.-.-.-.- = line of Output = Input + 5%; ______________ = tangent of steepest gradient: a = maximum profit; b = greatest return; c = maximum yield for a 5% return; d = maximum yield to break even.

Now consider the simplest case in which a land user wishes to use all his land for one crop or purpose. In fact (Figure 12) there are four soils on his property, of equal area and each offering a different response survey for that crop, but their differences are subtle. So he thinks that all his property is on soil C, that one that immediately surrounds his house and barns. He applies the input appropriate to soil C (I'_c) to his whole property and his total profit is $\Sigma\, a' = (a'_c - a'_A - a'_D + 0)$. He is not doing very well. A soil map would have shown him the limits of the four soils A–D, and experience or an extension officer could have given the response curves for A, B and D, to enable him to optimize his inputs separately ($I''_A + I''_B, I'_C, I''_C$) to produce a greater total profit of $\Sigma a'' = (a''_A + a''_B + a'_C + a''_D)$. Clearly $(\Sigma\, a'' - \Sigma\, a')$ is the benefit attributable jointly to the soil map and to whatever research or experience produced the three new response curves, provided it could not reasonably be assumed that the farmer did not (as here), or could not have perceived the soil differences himself. There are for example considerable areas round Oxford where gravel terrace and clay loam, or sandy loam and clay loam, or calcareous shallow rendzina and acid sol lessivé, are juxtaposed. When assessing what benefit local farmers have received from the local soil map it will be reasonable to assume that they will not have overlooked such large differences.

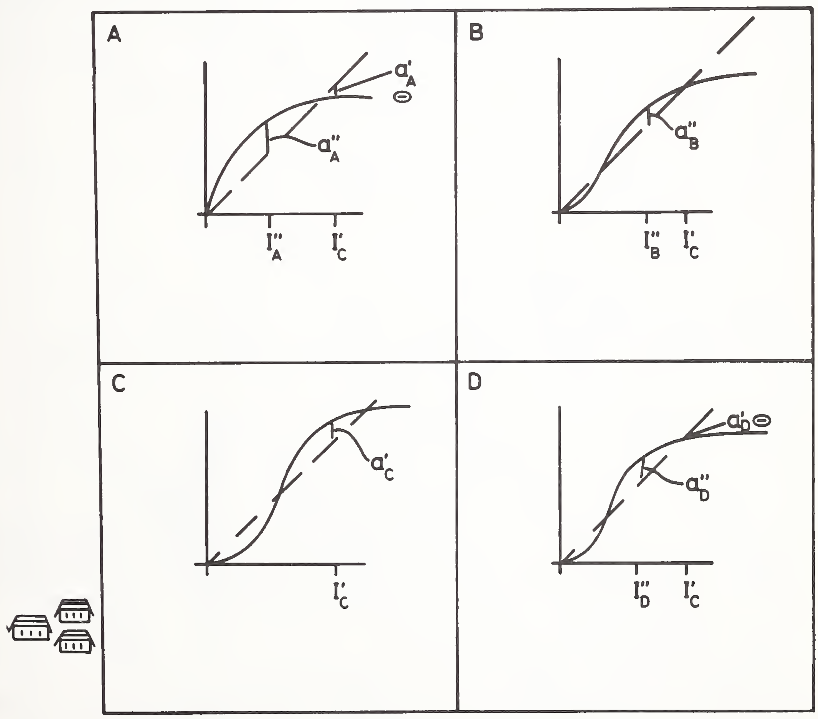


Figure 12. A farm on four soils A–D of equal area, with substantially different response curves for crop 1. In the first case the farmer assumed all his farm lies on soil C and applied to all soils the optimum input (I'_c) for soil C. In the second case he recognized the existence of four soils and applied to each soil the input that would maximize his profit (I''_A, I''_B, I'_C, I''_D). ----- are lines of output = input.

Not only will there be different response curves for every land use on one soil, but the differences between crops will be different on different soils (Figure 13). The land user has to choose. He may still do well with a single land use, but in this case better with crop C2 than C1 (as in Figure 12). But he may do better by mixing crops, for example C2 on soil A, C3 on soils B and C, C4 on soil D. Again, the value of the soil map is estimated from the maximum profit the land user can make when he uses it as a framework to optimize such choices compared with his maximum profit without it. There may of course be other constraints: soil erosion control may require that C1 not be grown except in rotation with C2 or C3, or C3 may occupy the land for 18 months, while only C4 occupies it for as little as six, so that C3 and C4 have to alternate, and so on. Nevertheless, my point stands—the benefit from a soil map is the extent to which the land user can increase his profit (or any of the other criteria of success mentioned above) by including in his decision-making the information that only the soil map and its supporting memoir can provide, either directly as in these examples, or indirectly by enabling extension officers to increase the precision and relevance of their research and advice.

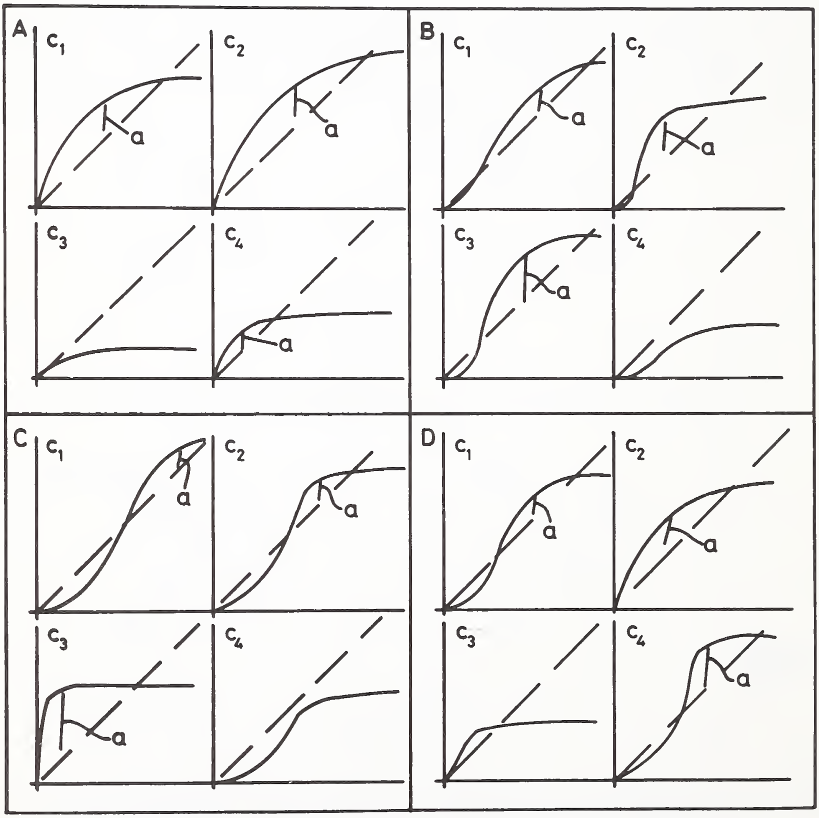


Figure 13. Four crops (cl is the crop in Figure 12) show very different response curves on the four soils on the farm of Figure 12; the farmer will achieve maximum profit for very different inputs.

This leads us to a further point. In practice the form of the response curve (or of the response surface it attempts to represent in two dimensions) for each land use on each soil depends on the values of a number of soil properties (the "relevant" properties above), none of which are wholly uniform over any of soils A–D. If the response curve of crop C1 on soil A were determined at 100 locations chosen to typify all delineations of soil A, the trials would produce a bundle of curves within an envelope (Figure 14), of which the breadth increases with the range of the values of the relevant soil properties within soil A, and hence with the breadth of the soil class and probably with the percentage of impurities in its mapping unit. The land user has to base his decisions on an assumed mean or median line (-------- in Figure 14), which leads him to input I. If the distribution of response curves about any point on the median is normal, then the outputs from input I on soil A will show the range described by the histogram; outputs above the "break-even line" represent profits and those below it represent losses. The total profit from input I to all delineations of soil A is then (☰☰☰)–(|||||||||). Had the land user used a single response curve, but based on trials on an untypical site (e.g. -.-.-.-. or .... on Figure 14) the same train of deduction would demonstrate negative or much smaller profits. Not only then is there a benefit from separating dissimilar soils, but the benefit will usually increase in proportion as the soil classes created show narrower ranges in their relevant properties.

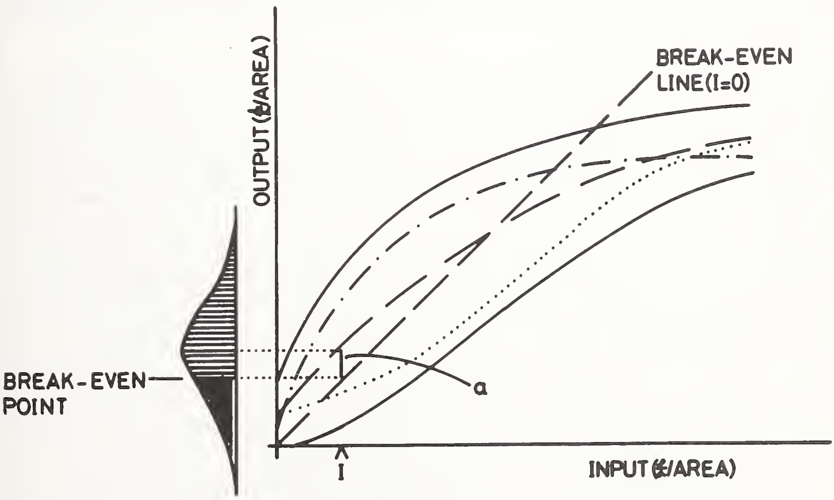


Figure 14. The response curve of one crop has been determined at 100 different sites on one soil class. The two outermost lines enclose all the results, and ---- is the medium response curve. On this basis the maximum profit (a) would be achieved with input I. The histogram illustrates the proportions of different outputs from the different delineations of the soil from a uniform input I; the area of it below the break-even point represents profit. Had the histogram been unsymmetrical, or had the farmer based his decision on a non-typical curve, his profit might well have been less.

Assume that the farmer chooses the combination of crop and management for each mapping unit that will give maximum profit on its dominant soil class. This management is likely to be suboptimal for any 'impurities,' or inliers of minority soil classes. Thus the total profit for the whole survey area will be less than optimal to the extent that simple mapping units contain impurities. Bie and Ulph (1972) explored the effect of mapping soils to greater purity on the cost-benefits of the survey.

Consider a landscape that contains five sub-areas (I-V), each occupied by two soil classes (S_1; S_2; S_3; S_4; etc.). There are twelve possible land use options (A–M). Their profits on the ten soils (Table 5) are plotted in Figure 15.

It seems unlikely that soil survey will be of much benefit in any landscape for which the land use options are represented by o on Figure 15, since these combinations show nearly the same profit on all the soils that a soil survey might separate. Even if he knew the limits of each soil the farmer would not be able to increase his return.

Conversely he may derive considerable benefit from soil maps of any landscape where the land use options are represented by x. In these landscapes the farmer will achieve less than optimal return by using any part of either of his soils for the group of uses which give small returns, and will therefore benefit from information which indicates more exactly the limits of each soil.

An existing soil map of the area shows that each sub-area contains two simple mapping units of equal area but of purities 70 and 50 percent respectively (Table 5). The procedure of Bie and Ulph (1972) was used to calculate the maximum farmer's profit if the whole area, or each sub-area separately, were re-surveyed:

(a) to raise the minimum purity for each mapping unit in steps from 50 to 90 percent;
(b) to raise the weighted average purity of the mapping units in each sub-area in steps from 60 to 90 percent.

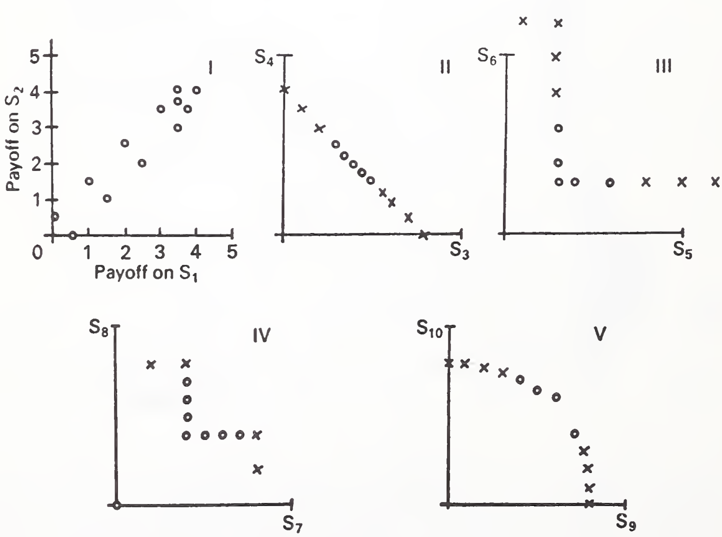


Figure 15. The payoffs (arbitrary units) from 12 land use options on the two soils present in each of five sub-areas in one landscape (see Table 5). (Bie, Ulph and Beckett, 1973; reprinted by permission of Oxford Univ. Press.)

Table 5. The profits for twelve combinations of land use and management (A–M) on the two profile classes in each of five sub-areas.

		I		II		III		IV		V	
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Area		**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Purity of soils as mapped so far		**0.7**	**0.5**	**0.7**	**0.5**	**0.7**	**0.5**	**0.7**	**0.5**	**0.7**	**0.5**
Payoff under managements A–M (arbitrary units)	A	0	0.5	0	4	1.5	1.5	2	2	3.95	0.5
	B	1	1.5	0.5	3.5	2	1.5	2.5	2	3.9	1
	C	2	2.5	1	3	3	1.5	3	2	1.5	3.75
	D	3	3.5	1.5	2.5	4	1.5	3.5	2	0	4
	E	0.5	0	2	2	5	1.5	4	2	2	3.5
	F	1.5	1	2.5	1.5	6	1.5	2	2.5	3	3
	G	2.5	2	3	1	1.5	2	2	3	3.5	2
	H	3.5	3	3.5	0.5	1.5	3	2	3.5	4	0
	J	4	4	4	0	1.5	4	2	4	2.5	3.25
	K	3.5	3.75	1.75	2.25	1.5	5	1	4	3.75	1.5
	L	3.75	3.5	2.25	1.75	1.5	6	4	1	1	3.9
	M	3.5	4	2.75	1.25	0.5	6	0	0	0.5	3.95

(Total area = 5)
(Weighted mean = 0.6)

As shown in Figure 15, the economic impact of suboptimal management practices are greatest in sub-areas II and III, so that detailed soil surveys of these sub-areas will be the most profitable. All land uses yield similar profits in sub-area I, so there will be insignificant benefits. According to how the purity to be achieved depends on the cost of the survey, it might be profitable to survey sub-areas II and III to higher purity than areas IV and V.

The procedure has been applied (Bie, Ulph and Beckett, 1973) to peach-growing in the Uanco (NSW) area in Australia, for which economic data (Table 6) is available for the three main varieties of Cling peaches on each of 18 soils. The analysis assumes that the impurities in each mapping unit were in proportion to their occurrence in the landscape as a whole. It also assumes that optimum input is independent of variety of soil, so that gross return is proportional to profit.

Figure 17 indicates how the gross returns would increase (over and above the $757/acre achieved if Golden Queen Cling was grown on every soil) as the purity of each mapping unit is raised from 20 to 90 percent. In this case the graph is nearly linear for purities between 50 and 90 percent. There must be a ceiling imposed by the farmers' inability or unwillingness to plant single trees on small inliers of different soils.

Similar calculations can be performed on the yield data in many survey reports, provided only that the relevant unit costs for input and output can be obtained. Approximate estimates of the benefits from soil survey to various purities may be based on soil data obtained during the presurvey reconnaissance and on agronomic data obtained from economic surveys and extension officers' local knowledge.

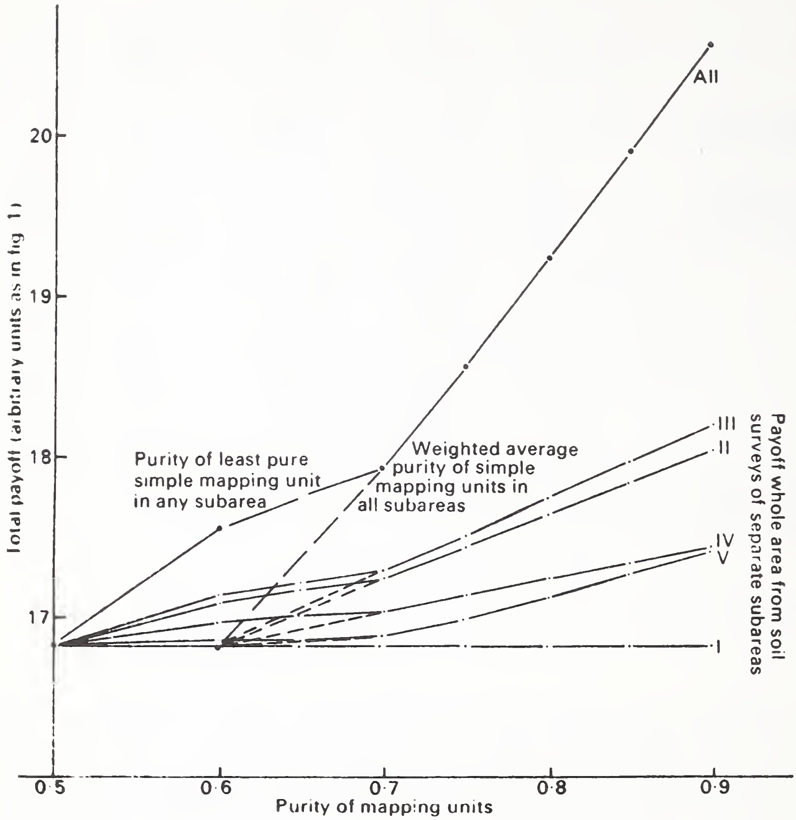


Figure 16. The increased payoff (arbitrary units) results from the more exact matching of land uses A–M (Table 5) to soil class that may be attained as the "purity" of soil mapping units is increased by more detailed survey. There are two soils in each area, of which one was already mapped to 70% purity and the other to 50% purity: the areas may be resurveyed to bring the purity of the latter up to the level of the former, or to increase the average purity from its initial value of 60% (Bie, Ulph and Beckett, 1973; reprinted by permission of Oxford Univ. Press).

Table 6. Gross return (in A$ per acre) for three varieties of peaches.

Soil type	Proportion of area	Golden Queen Cling	Phillip Cling	Pullar Cling
1	0.028	1367	1293	1237
2	0.004	1128	958	1543
3	0.038	1427	1293	1696
4	0.056	1207	498	919
5	0.046	1082	1073	824
6	0.009	820	843	306
7	0.069	923	862	848
8	0.046	900	690	848
9	0.028	661	709	542
10	0.017	1036	891	1154
11	0.048	661	354	236
12	0.186	729	498	589
13	0.103	718	661	954
14	0.099	558	584	565
15	0.038	615	335	94
16	0.105	410	402	283
17	0.027	433	364	0
18	0.055	353	421	59

From Bie and Ulph, 1972.

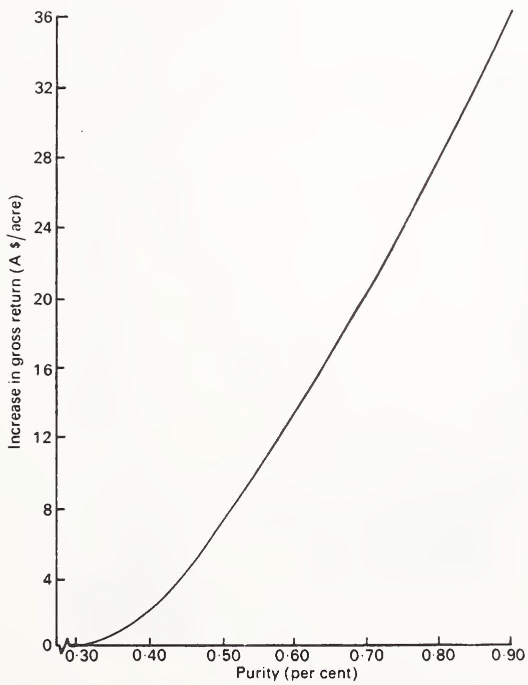


Figure 17. The calculated increase in gross returns (A$ per acre) as increasingly detailed soil survey enables farmers to adjust peach variety to soil type more precisely (Bie, Ulph and Beckett, 1973; reprinted by permission of Oxford Univ. Press).

COST-BENEFIT RATIOS

The general form of the relationship between the cost of a soil survey and its precision or the uniformity of relevant soil properties within its mapping units is known (Figure 18): it represents the Law of Diminishing Returns. Clearly the cost-benefit ratio (Figure 18) is very sensitive to the form of the profit-precision relationship and the general form of this relationship is less well known. Figure 18 assumes that it is of the same form as Figure 17. The relative magnitude of the units on the cost and payoff aces are not certain, and the land user will not take notice of discrepant areas of less than some critical size, but none of these uncertainties present inseparable problems.

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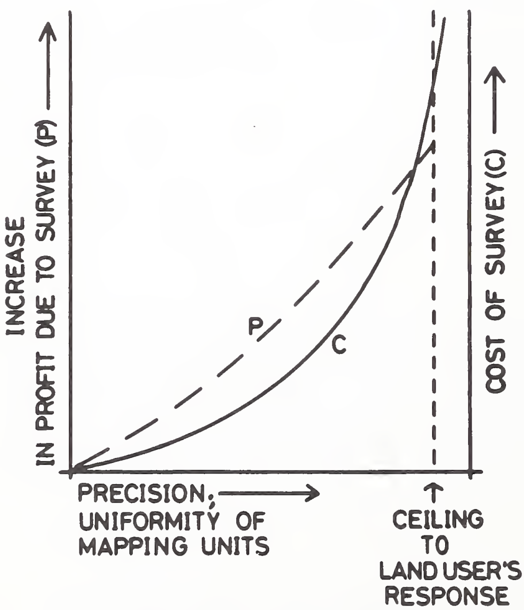


Figure 18. The uniformity of "relevant" soil properties within mapping units increases with survey cost: the benefit from the survey increases with the uniformity of its units. Unfortunately the forms of the two curves are not known for the same survey.

LITERATURE CITED

BECKETT, P. H. T. 1967. Lateral changes in soil variability. J. Aust. Inst. Agric. Sci. 33:172–179.

BECKETT, P. H. T. 1971. The cost-effectiveness of soil survey. Outlook on Agric. 6:191–198.

BECKETT, P. H. T., and S. W. BIE. 1975. Reconnaissance for soil survey. I. Pre-survey estimates of the density of soil boundaries necessary to produce pure mapping units. J. Soil Sci. 26:145–154.

BECKETT, P. H. T., and S. W. BIE. 1978. Use of soil and land system maps to provide soil information in Australia. Div. Soils. Tech. Paper. No. 33. CSIRO, Australia.

BIE, S. W. 1972. The relative efficacy of different procedures for soil survey in developing countries. D. Phil Thesis, Oxford University.

BIE, S. W., and P. H. T. BECKETT. 1970. The costs of soil survey. Soils and Fertilizers 33:203–217.

BIE, S. W., and P. H. T. BECKETT. 1971a. Quality control in soil survey. I. The choice of mapping unit. J. Soil Sci. 22:32–49.

BIE, S. W., and P. H. T. BECKETT. 1971b. Quality control in soil survey. II. The costs of soil survey. J. Soil Sci. 22:453–465.

BIE, S. W., and A. ULPH. 1972. The economic value of soil survey information. J. Agric. Econ. 23:285–297.

BIE, S. W., A. ULPH, and P. H. T. BECKETT. 1973. Calculating the economic benefits from soil survey. J. Soil Sci. 24:429–435.

BURROUGH, P. A., M. G. JARVIS, and P. H. T. BECKETT. 1971. The relation between cost and utility in soil survey. J. Soil Sci. 22:359–394, 466–489.

KLINGEBIEL, A. A. 1966. Costs and returns of soil surveys. Soil Conserv. 32:3–6.

VINK, A. P. A. 1963. Planning of soil surveys in land development. Publs. Int. Inst. Reclam. Improv. 10.

WESTERN, S. Soil survey contracts and quality control. Oxford University Press. (In press.)

Planning Objectives and the Adequacy of Soil Resource Inventories

A. Van Wambeke

The adequacy of a soil resource inventory for development planning can only be appraised in a meaningful way when the information given by the survey is matched against the requirements of specific planning objectives.

During the course of the study of soil resource inventories and development planning, it soon became obvious that planners deal with many aspects of development, which vary greatly in kind, degree, and precision. The concerns of planners relate to the questions "What? How? Where?" concerning the presence, performance, response to management, and feasibility of resource development. The inquiries may be for inventory purposes or may be action oriented. For each answer to their questions, planners require reliability and precision.

Soil scientists provide information through soil surveys. The simplest analysis of soil maps would start with lines and symbols or colors. Lines should answer questions about location, or "where?" Symbols and colors should lead to information about "what?" or "how?" For this reason soil survey characteristics are discussed under two headings: location and information requirements.

LOCATION REQUIREMENTS

Areas of interest to planners

Most but not all descriptions of soil resources include maps which indicate the location of specific soils. Planning often involves siting or the assignment of objects or operations to well-defined areas. These areas are of interest to planners because they are uniform in either topography or soil properties, respond uniformly to management, or present the same development needs.

In this paper, the term "area" refers to actual land areas on the ground. When they are represented to scale on maps, the boundaries enclose "delineations."

The "planning area" is the entire land surface for which a plan is made. This may be a region in which a land use plan shows that different parts are best used for different purposes. It may be a tract of cropland in which different parts need different management. Conceivably some planning areas are homogeneous enough that the plan would assign the same use or even the same management to all parts.

The term "operational area" is proposed for tracts of land where specific sets of activities related to land use will be conducted.

Individuals or groups of individuals may reserve certain areas for use by economic units functioning under the same operational control. It may be the area which is utilized by one farm, or the land cropped by a farmers' community, or the domain controlled by a plantation.

The term "operational area" is used as a general designation for parts of a planning area which will be administered as one economic or social unit. In this context operational areas by definition cannot be larger than the planning area. In certain cases a minimum-size operational area may be recognized. It is the operational area of land which for practical consideration cannot be reduced in size without loss of profits or other advantages. For example, an oil palm factory needs a minimum supply of palm nuts to achieve maximum efficiency. In a land use plan designed to identify areas suitable for farming the "minimum operational area" might be the smallest parcel that would realistically support a farm unit. The minimum operational area is equivalent to Smyth's (1977) minimum area of planning interest.

The term "management area" is used for areas identified on the basis of the type of soil management which is applied to them. A field planted to corn receiving the same treatment is a management area. Operational areas and management areas may not, and usually do not, coincide with soil patterns. Many factors other than soil may dictate their size and shape for practical land use and management.

The term "performance area" is used for tracts within which one may predict relatively uniform soil performance under a single system of management for a given use. The boundaries of performance areas generally coincide with soil boundaries, although those boundaries may enclose areas of two or more kinds of soil that perform alike for a given use. Performance areas may vary for different uses.

The term "soil performance" is used for the yield or other output obtained from a soil in response to management under a given land use. A soil having properties good for a given use has the qualities to "perform" well in that use. If a critical soil property severely limits a given use, the soil would "perform" poorly. The term not only describes the land use quality of a soil as it is found in nature but also takes into account the qualities resulting from soil changes imposed by men.

Performance for growth of plants is expressed in terms of actual or average yields per unit area; it is related to the concept of potential by the equation: potential equals performance minus costs to produce the performance yield, expressed in monetary units.

The sizes of all of the kinds of areas discussed above are expressed in units of land measurement, such as hectares of square kilometers. Delineations are usually measured in square centimeters on the map. To avoid confusion, one should refer to planning delineations, operational delineations, management delineations, and performance delineations when referring to maps. A set of equations to convert the sizes of land to sizes of delineations on maps as a function of map scale are given below:

m	:	linear distance on map in cm
a	:	area on map in sq cm
g	:	linear distance on ground in cm
Ah	:	area on ground in ha
Ak	:	area on ground in sq km

s : scale denominator (1:s)
G : g in meters = g/100

$$g = sm$$

$$G = \frac{sm}{100}$$

Conversion of area on map (cm^2) to area on ground (ha) or vice versa

$$Ah = \frac{a\,s^2}{10^8} \quad \text{and} \quad a = \frac{Ah \cdot 10^8}{s^2}$$

Conversion of area on map (cm^2) to area on ground (km^2) or vice versa

$$Ak = \frac{a\,s^2}{10^{10}} \quad \text{and} \quad a = \frac{Ak \cdot 10^{10}}{s^2}$$

Scale as a function of the ratio between areas on ground (ha or km^2) and area on map (sq cm)

$$s = 10^4\sqrt{\frac{Ah}{a}} \quad \text{and} \quad s = 10^5\sqrt{\frac{Ak}{a}}$$

Relation between map scale and size of area of interest

There are economic reasons to reduce scales of soil maps as much as possible; costs of surveys are proportional to the square of the scale. However, there is a limit for the reduction of maps: the delineations of areas in which planners are interested should remain legible; this is achieved as long as most delineations are larger than 0.4 sq cm (Soil Resource Inventory Group, 1977); optimally the average size should be larger than ± 1.5 sq cm.

The adequacy of scales can be checked against the size of the delineations of planning interest on the map. The minimum scale of a map is defined by the size of the smallest area of interest the planner wishes to identify on the map: it is the smallest of either the operational, the management, or the performance delineation which will first reach the 0.4 sq cm size limit when maps are reduced.

An example may help to clarify the concepts and illustrate the use of areas of interest in adequacy appraisals. Assume a territory of one million hectares. An agency is asked to select the best locations for rural communities which would need 10,000 ha each. Each farmer in a community would need 50 ha of land to be subdivided into fields no smaller than 2 ha. Soil maps at 1:100,000 are available on which the performance delineations are on average 2.3 sq cm large. There are aerial photographs at a scale 1:40,000.

According to the adequacy standards explained above, the map at 1:100,000 is adequate for selecting the best sites for the communities since the critical performance delineation is larger than the conventional 0.4 sq cm set for legibility; the performance delineation (2.3 sq cm) is in this case the delineation which corresponds to the smallest area of interest (2.3 is smaller than 100).

The sitting of the 50 ha plots within the community lands would need additional maps. Indeed, the critical area of interest, which is now represented by the operational delineation (the operational area of 0.5 is smaller than the performance area of 2.3 sq

cm) is close to the 0.4 sq cm limit, and far below the optimal size of 1.5 sq cm requested for legibility. For making farm plans which would indicate the location of the 2 ha fields, the management delineations on the aerial photographs at 1:40,000 scale would be 1.25 sq cm, slightly below the optimum size for map delineations. If the performance of the crops to be planted in the fields could be predicted as uniform in each farm, the 1:40,000 aerial photographs would be adequate to indicate the location of the 2 ha fields.

INFORMATION REQUIREMENTS

Once the soil data that are recorded in surveys are given to planners, their main concerns relate to two kinds of information: (1) the extent to which the inventory permits identification of limiting factors for the intended land uses, and (2) the variability of these limiting factors within each map unit.

To respond to these concerns, a precise understanding of the types of land uses which will be introduced in the planning area is needed. Alternatives should be discussed with agronomists or other resource development specialists, but specific soil limitations to the projected land use should be recognized. They form the third set of data needed to assess the adequacy of information provided by soil resource inventories.

The three components are briefly discussed below:

Diagnosis of land use requirements

The judgment of an agronomist or soil scientist familiar with plant requirements and management systems is critical. For each specific objective a list of limiting soil properties must be compiled, and their relation to crop production or feasibility of development assessed as closely as possible.

The degree of detail needed varies with the degree of specialization of the development objectives. As an example the limiting soil properties for oil palm are given in Table 1. A table such as this sets critical limits for suitability within a particular project and serves two purposes in the adequacy study of soil resource inventories: (1) it gives the soil properties which should be described in the soil survey report, and (2) it permits an evaluation of the percentage of suitable land in the planning area.

Usually, this type of information is not easily found in the literature; most frequently the critical limits have to be defined for each project.

Table 1. Limiting soil properties for tropical tree crops (oil palm example). (Sys, 1976)

Properties to be evaluated	*Critical limits*
1. Topography (slope)	Not more than 30% slope
2. Drainage	Not more poorly drained than imperfectly drained
3. Flooding	Not more than slight flooding
4. Texture	Not lighter than sandy loam
5. Stoniness	Not more than 75%

6. Effective soil depth	Not less than 50 cm
7. Cation exchange capacity	Not less than 16 meq/100 g of clay; no net positive charge
8. Base saturation	Not less than 15% in the surface horizons
9. Organic matter	Not less than 0.8%

Information on limiting factors

There are several ways to check the presence of data related to limiting factors in soil resource inventories. Many surveys, but not all, either have condensed the information in soil classification systems, or in interpretative tables. These procedures may facilitate the identification of properties which have to be taken into account in the feasibility or suitability evaluation. In most instances, however, the adequacy study will have to check each description of each individual map unit for relevance to specific objectives.

In the soil resource adequacy study proposed by Cornell's group, all soils for which no information on required limiting factors is given are categorized as "unknown." The soil units or parts of them which have all qualities above the critical level are called "suitable." All others are termed "limiting."

Information of map unit composition

The planner should be informed as to whether uniform responses to the development actions can be expected in each map unit. The soil resource inventory should provide an estimate of the within-boundary variability of limiting factors. As in the previous section, in some survey procedures, the name of the mapping unit may give some indications about its composition. In many cases however, even when all reported data are true, the internal variability may not be reported.

The Soil Resource Inventory group at Cornell proposes to categorize soil units about which no information on variability is given, or which contain more than 40% undescribed inclusions, as "unknown." Those which contain less than 15% inclusions of dissimilar soils are qualified as "uniform." All others were considered "non uniform."

There are three components in the assessment procedures of map unit composition: (1) the adequacy of the information given in the survey report about the variability of limiting factors within each unit. This does not need ground checking; (2) the evaluation of the map unit composition in the field either by additional, more detailed mapping, or statistical sampling and, (3) the correspondence of soil information as given in the survey and the actual occurrence of soil properties in the field.

Adequacy of soil resource information, an example

The combination of the uniformity and suitability concepts, explained above, with the "unknown" parts of mapped areas, can be used to define appraisal classes. The soil resource inventory group at Cornell has been testing five classes of areas described briefly as follows:

> Uniform-limiting (U-L), Uniform-suitable (U-S), Non uniform-predominantly suitable (N-PS), Non uniform-predominantly limiting (N-PL), and Unknown (U).

The U-L and U-S areas correspond to the performance areas previously defined in this text. A methodology to estimate the percentage of these classes on a map has been described by Forbes (1977).

The use of these classes in adequacy studies can be illustrated by an example in which the following results of area estimates were obtained:

U-L:	Uniform—Limiting: 26%	(1)
U-S:	Uniform—Suitable: 16%	(2)
N-PS:	Non uniform—predominantly suitable: 37%	(3)
N-PL:	Non uniform—predominantly limiting: 13%	(4)
U:	Unknown: 8%	(5)

It would mean that the information given by the map, provided it were accurate (no field checking done yet), is adequate is 42% of the planning area (1 + 2); it would be necessary to conduct an additional survey in 45% of the area (3 + 5). It would not be worthwhile to investigate the composition of the soil units in 13% of the area (4), because most of the land in this part is unsuitable for the intended land use.

SUMMARY AND CONCLUSION

The two examples given in this paper illustrate the use of objective criteria in the evaluation of the adequacy of soil surveys. They only considered two components: scale and map unit composition. A complete evaluation should also include the quality of base maps, ground truth, etc.

The criteria regarding location requirements determine for given standards of base maps how well the question "where?" is answered. This type of adequacy is important for siting an area on the ground, or identifying a delineation on the map.

How well the question "what limitations?" can be answered, is covered by the information criteria. It also gives an indication of the amount of additional surveys which would be needed to arrive at a complete diagnosis of the planning area.

The methodology, which is only a part of a complete soil resource inventory evaluation, is applicable where a specific objective for utilizing the survey has been selected and when the critical soil properties for that particular land use are known. When more than one objective for utilization is involved in one evaluation, the criteria for defining sets of limiting factors still has to be worked out. Suitability scales for soils in multipurpose projects cannot be used in the adequacy study, since all soils are suitable for something.

LITERATURE CITED

Forbes, T. 1977. Draft copy of guidelines for soil survey characterization. Department of Agronomy, Cornell University, Ithaca, NY.

Smyth, A. 1977. The objectives of soil surveys of various intensities. p. 25–36. *In* Soil resource inventories: Proceedings of a workshop held at Cornell University, April 4–7, 1977. Agronomy Mimeo No. 77–23. Dept. of Agronomy, Cornell Univ., Ithaca, NY.

Soil Resource Inventory Group. 1977. Soil resource inventories: Proceedings of a workshop held at Cornell University, April 4–7, 1977. Agronomy Mimeo No. 77–23. Dept. of Agronomy, Cornell Univ., Ithaca, NY.

Sys, C. 1976. Land Evaluation. Parts I and II. State Univ. of Ghent. International Training Center for Post-Graduate Soil Scientists. Ghent, 1976.

PART TWO

ADEQUACY OF SOIL RESOURCE INVENTORIES

Section II

Methods to Determine Adequacy of Surveys

Soil Survey Report and Map Checklist

T. R. Forbes and H. Eswaran

The Soil Resource Inventory Study Group has compiled a Soil Survey and Map Checklist on which is recorded relevant soils and map data. The checklist is useful from several different points of view.

First, given the large number of different kinds of soils report formats and map presentations, the checklist provides a concise summary of the report and map for later reference. Since the checklist is standardized, the kind of information extracted from the report and map will be the same no matter what the original format. This aspect may be particularly useful to administrators who need a short summary of pertinent facts for land use planning decisions.

Second, a collection of checklists form a useful inventory of existing soil resource inventories for any given continent, country, region or any other desirable geographic subdivision. Many governmental ministries in less-developed countries, and funding agencies in developed countries, are often overwhelmed with years of project reports, feasibility studies and other materials which may include soil resource inventory information. Rapid and efficient access to these materials is often lacking and in the case of large funding agencies, the volume of materials that need to be researched for any given geographic area or country may be prohibitive. Generally, the final result is an underutilization of valuable reports and studies for assessing the effectiveness of past development projects and for planning effective future development projects. Or it may result in a duplication of work since sponsors of future projects may not be aware that a usable soil resource inventory already exists in a given area. (This is particularly a problem in less-developed countries where many soil resource inventories are carried out as a part of a specific project that is not published in a government report).

Third, the checklist can be used an an instrument for soil resource inventory characterization and/or evaluation for specific objectives. The checklist includes a 4-step characterization methodology flowchart.

CHECKLIST: SUMMARY OF MAJOR SECTIONS OF THE SOILS REPORT

The first section of the checklist summarizes bibliographic and background material which would be useful for report writing and just generally getting an overview of the

kinds of materials which the soil survey report contains (see Section 1, Soil Survey Report and Map Checklist at end of this paper).

The second section of the checklist concerns the objectives of the survey. The first set of objectives includes three major headings of land use planning:

a. master planning or broad land use planning,
b. project planning,
c. operational planning.

Master planning can be subdivided into three categories: national, regional, and cultural systems. Project planning involves the selection of sites for groups of crops based on specific management requirements. The soils information in this case should be specific enough to assess suitability for broad groups of plants in a cultural system. Operational planning designs land management systems within tracts that are assigned to specific uses. Operational plans detail what, how, and when management inputs are needed for satisfactory land use. Elements of soil performance are primary criteria for this kind of planning. General or cross-objectives include those outside specific planning objectives. Such objectives may include scientific advancement, the gathering of data for soil classification or other related scientific disciplines.

The third section of the checklist categorizes the soil survey according to map and legend characteristics. Characteristics of the categories of soil surveys are as follows (USDA, 1974):

Exploratory:

a. compiled without field identification of soils
b. soil descriptions inferred from limited information on climate, geology, landforms
c. scale <1:650,000
d. map units defined very broadly or incompletely
e. no limits on the amount or percentages of inclusions
f. objectives: compilation of known data for nation or continent on which to base further, more detailed soil studies
g. topographic or aerial photo base; no topographic or aerial photo base

Macro-reconnaissance survey:

a. map units identified by limited observations of the soils within the area
b. no precise location of soil boundaries
c. scale 1:130,000 to 1:650,000
d. map units are associations of higher categories or broadly defined taxa
e. no limits on the amount or percentage of inclusions
f. minimum-size delineations as small as 50 km^2 (500,000 ha)
g. planning units as large as 100,000 km^2
h. objectives: planning for large states, nations, and continents
i. identification of the soils is mainly based on field data but in some cases supported by laboratory data

Meso-reconnaissance:

a. boundaries determined by soils observations
b. scale 1:65,000 to 1:130,000
c. minimum-size delineations 100 to 4,000 ha, but usually larger

d. planning units 1,000 to 10,000 ha or 20,000 to 1,000,000 km^2
e. no limits on the amount or percent of inclusions
f. map units are associations of higher categories of taxa (in the USDA system these may include associations of families, subgroups, great groups, etc.)
g. field methods: random traverses with detailed sampling blocks
h. objectives: planning for states, small nations or regions; soils delineated for possible use but not management
i. minimum or least-size delineations are 2 to 100 ha

Macro-detailed surveys:

a. boundaries determined by soils observations
b. scale 1:26,000 to 1:65,000
c. smallest delineations are 10 to 20 times the size of areas that could be delineated at the minimum legible scale
d. planning units are usually 100 to 10,000 ha or km^2
e. no limits set on inclusions at smaller scales with limits on inclusions at approximately 30% at larger scales
f. map units are usually predominantly consociations at the larger scales and associations at the smaller scales. (The USDA system may include consociations or associations of series, families and subgroups.)
g. field methods: traverses to detect minimum-size delineation of contrasting soils (with detailed sampling blocks)
h. objectives: delineate for medium-sized or extensive operating units (forests, rangeland, large farms), not to site structures or operational planning for intensive uses
i. smallest delineations are commonly 4 to 5 times the size of areas that could be delineated at the minimum legible scale

Meso-detailed surveys:

a. scale 1:13,000 to 1:26,000
b. minimum or least-size delineations are 0.5 to 2 ha (smaller areas use spot symbols)
c. planning units are usually 5 to 2500 ha
d. inclusions in map units should be 20%
e. map units are usually consociations (may also have some complexes or associations)
f. in some cases the smallest delineations may be two times the size of the areas that can be delineated legibly at the minimum legible scale
g. field methods: direct observations with traverses close enough to detect contrasting areas
h. objectives: covers operational planning for moderate intensively used management units such as farms and ranches (larger scales), more extensively used units, such as forests, rangelands, etc.; or selection of areas for more detailed surveys for intensive operational units

Ultra-detailed surveys:

a. scale >1:13,000
b. minimum or least-size delineations are 0.1 to 0.5 ha (smaller areas of limiting inclusions shown by spot symbols) 0.001 to 0.6 ha

c. planning units are usually 1 to 500 ha
d. inclusions in map units should be <20%
e. map units are consociations (with some complexes at the smaller scales)
f. field methods: direct examination with field traverses to pick up the limiting areas
g. objectives: planning and siting for small areas such as experimental areas, truck gardens or housing sites

Kinds of map units are defined according to United States Department of Agriculture (USDA), Soil Conservation Service (SCS) standards.

The results of the determinations of map pattern and map unit composition analyses are recorded in the last categories of this section. To understand the implications of these results the reader would have to compare them to the appropriate tables given in the handbook of soil resource inventory characterization of the Soil Resource Inventory Study Group (Arnold et al., 1978).

The fourth section of the checklist characterizes the methodology of preparation of the soil survey. These categories should complement or give further information on the kind of soil survey as described in the third section of the checklist. The determination of the number of reference points on a given area of the base map can be made by criteria set forth in the handbook of soil resource inventory characterization by the Soil Resource Inventory Study Group (Arnold et al., 1978).

The fifth section of the checklist covers the results of field checking which may have been completed by the person(s) characterizing or evaluating the soil resource inventory report and map. The theory and methodology of field checking is discussed in the handbook of soil resource inventory characterization by the Soil Resource Inventory Study Group (Arnold et al., 1978).

The sixth and final section of the checklist is a blank page for a narrative characterization or evaluation. This may indeed be the most useful section of the checklist.

In compiling the checklist and characterizing approximately 200 existing soil resource inventories from around the world it was found that much information was not clearly presented and had to be deduced from explanations given in the particular report or map. However, it is suggested that future soil resource inventories clearly state this information somewhere in the body of the text. Results of characterizing over 200 soil resource inventories from around the world are given in Table 1.

LITERATURE CITED

Arnold, R. W., A. Van Wambeke, H. Eswaran, and T. R. Forbes. 1978. Guidelines for soil resource inventory characterization (draft). Dept. of Agronomy, Cornell Univ., Ithaca, NY.

Eswaran, H., T. R. Forbes, and M. C. Laker. 1977. Soil map parameters and classification. p. 37–59. *In* Soil resource inventories: Proceedings of a workshop held at Cornell University, April 4–7, 1977. Agronomy Mimeo 77–23. Dept. of Agronomy, Cornell Univ., Ithaca, NY.

United States Department of Agriculture, Soil Conservation Service. 1974. Soil survey manual, Rev. ed. (4th Draft, 74–75). USDA, SCS, Washington, DC 20000.

GLOSSARY

Association: A geographic mixture of areas of two or more distinctive kinds of soil, or of a soil and a kind of miscellaneous area. The areas of principal components of soil associations can be delineated separately by detailed survey methods at map scales of about 1:20,000 (USDA, SCS, 1974).

Consociation: A mapping unit in which only one identified component of soil (plus allowable inclusions) occurs in each delineation.

Least-size delineation: A delineation which is so small that it cannot contain a two or three digit mapping unit symbol. Features smaller than this, and of importance, are indicated by spot symbols.

Map index of maximum reduction: The factor by which a map may be reduced before it loses legibility. It is computed by the square root of the ratio of average-size delineation to minimum-size delineation.

Map unit composition: Refers to the extent to which limiting soil properties for a specific land use objective are given in descriptions of map units such as profile descriptions, analytical data, land capability classifications, interpretation tables and others.

Minimum-size delineation: The smallest area that still can be legibly indicated on a map. It has an arbitrary area of 0.4 cm^2 on the map.

Soil Survey Report and Map Checklist

I. General Bibliographic and Background Information

Date of report: ____________

No. of map sheets: ____________

Country: ____________

Title of report: ____________

____

____

____

Report prepared by author(s) (last name, first name): ____________

____

Map scale: ____________

Area (km²): ____________

Book reference—(library call no. or other location): ____________

____

Publisher: ____________

____

City (publisher): ____________

____

No. of pages: ____________

Other bibliographic information (report no.; gov't agency, division, etc.): ____________

____

Report accompanied by the following maps:

Type	No	Yes	Actual Scale	Scale Code*
Geology			G	
Vegetation			V	
Physiography			P	
Climate			C	
Land use (present)			U	
Land capability/ potential			L	
Irrigation potential			I	
Erosion hazard			E	
Other			O	

Scale code*			
1	—		1:12,999
2	1:13,000	—	1:25,999
3	1:26,000	—	1:59,999
4	1:60,000	—	1:129,999
5	1:130,000	—	1:259,999
6	1:260,000	—	1:649,999
7	1:650,000	—	—
8	None indicated		

Report accompanied by the following information:

Type	No	Yes	
Geology			G
Vegetation			V
Physiography			P
Climate			C
Land use (present)			U
Land capability/ potential			L
Irrigation potential			I
Erosion hazard			E
Other (specify)			O

Characterization done by: ____________

Characterization completed on: ____________

Soil Survey Report and Map Checklist

II. Objective(s) of Survey[a]

Indicated	Yes	No
Master Planning (broad land use planning)		
National planning and inventory		
Identification of broad development regions for purposes below		
Cropping		
Grazing		
Range lands		
Forestry		
Wildlife and recreation		
Watersheds		
Urban or settlement area		
Others (specify):		
Regional Planning and Inventory		
General (selection of promising areas for a specific purpose)		
Cultural systems general planning including:		
Shifting cultivation		
Wet culture (paddy rice, sugarcane, etc.)		
Rainfed permanent culture		
Irrigation dryland culture		
Other (specify):		
Grazing		
Dryland		
Irrigated		
Rangelands		
Forestry		
Wildlife and recreation		
Settlement areas		
Assess drainage requirements		
Background for soil conservation or reclamation program		
Delineate areas for watershed development		
General location of transport infrastructure, secondary industries or urban development		

[a]Add asterisks (*) to "check mark" if you believe that a particular objective is implied or that the report seems to meet the requirements for that particular objective.

Soil Survey Report and Map Checklist

Project planning[b]
Siting areas of rainfed crops and pastures (based on specific management requirements)—(specify crops or pastures):
Irrigation feasibility
Rangelands
Forestry
Wildlife and recreation
Land settlement sites
Engineering and urban purposes
Others (specify):
Operational Planning[c]
Irrigation siting (specify crops):
Siting experiment stations and field plots (specify crops):
Rainfed crops for which management systems are indicated (specify):
Engineering and urban uses
Site roads and pipelines
Site foundations, sewers, septic tanks
Landscaping plans
General or Cross-Objectives
Scientific advancement
Provides data for soil classification and genesis
Provides data for geomorphology, geography or ecology
Others (specify):
III. Kind of Survey, Map and Legend Characteristics
Exploratory Survey (compiled without identification by original observations in the area. Compiled from limited information on climate, vegetation, geology and landforms)
Topographic or airphoto base
No topographic or airphoto base
Macro-reconnaissance survey (mapping units are identified by observations of the soils within the area, but the soils boundaries are largely compiled from other sources)

[b]Soils information should be specific enough to assess the suitability for broad groups of plants in cultural systems.

[c]Soil information should be specific enough to assess the suitability for specific crops under a particular system of management.

Soil Survey Report and Map Checklist			
Identification of the soils is mainly based on field data			
Identification of the soils is supported by laboratory data			
Meso-reconnaissance survey			
Macro-detailed survey			
Meso-detailed survey			
Ultra-detailed survey			
Kind of Survey—indicated in report by authors	Yes		No
Specify author's designation:			
Kind of Map Units			
USDA or translated to USDA (if translated by checker, mark with asterisk*)			
	Intensity level[d]		
	1	2	3
Consociations			
Associations			
Complexes			
Undifferentiated group			
Map Unit Components			
Number of categories			
USDA equivalents	Yes		No
Phases of soil series			
(specify phases):			
Soil series			
Phases of soil families			
(specify phases):			
Soil families			
Phases of subgroups			
(specify phases):			
Soil subgroups			
Phases of great groups			
(specify phases):			
Soil great groups			
Phases of suborders			
(specify phases):			
Soil suborders			
Phases of soil orders			
(specify phases):			

[d]Asterisk (*) notes the predominant mapping unit

Soil Survey Report and Map Checklist
Soil orders
Other:
Not comparable
Taxonomy—Classification System
Comprehensive
Non-comprehensive (name):
"Tailor-made" for study
No taxonomic system
Land capability classes
Soil potential classes
Map Texture or Pattern
Average-size delineation (cm²)
Average-size delineation (ha)
Largest size area delineated (estimate, ha)
Use of spot symbols
Index of maximum reduction
Reduced scale
Actual published scale
Map Unit Composition
Objective for background of map unit composition
List of limiting factors for specific objective:
Percent uniform-limiting
Average-size delineation, uniform-limiting
Percent uniform suitable
Average-size delineation uniform suitable
Percent nonuniform-predominantly limiting
Average-size delineation, nonuniform predominantly suitable
Percent nonuniform predominantly suitable
Average-size delineation, nonuniform predominantly suitable
Percent nonuniform predominantly suitable
Percent unknown
Average-size delineation, unknown
IV. Methodology of Preparation
Average number of profiles sampled per map unit
Type of analyses completed for most profiles
Routine
Fertility-related properties and routine

Soil Survey Report and Map Checklist
Special properties (salinity, acid sulfate etc.) & routine
Special properties (mineralogy etc.) and routine
Other (specify):

Usefulness of base map for location

2 reference pts. within circle (see Chap. 3)	low
2–5 "	moderate
6–8 "	high
9 "	very high

Type(s) of base map
Airphoto
Topographic
Other (specify):
Scales of base map (specify):

Field Methods

Number of observation points per cm² on field map, indicated (use code given below)

1 = 1 pt.
2 = 2 pts.
3 = 2–4 pts.
4 = 4–8 pts.
5 = 7–8 pts.
6 = not indicated

Type of survey
Rigid grid
Rigid and with airphotos
Grid survey with additional observations to locate boundaries
As above but with aerial photos
Random survey
Random survey with airphotos
If soil map was generalized
Effective scale (specify):
Legend determination
Fixed prior to survey with minor alterations
Fixed prior to survey with major alterations
Made during progress of survey
Not indicated
V. Field Evaluation
Random spot checks made for
identification of soils
results:

Soil Survey Report and Map Checklist

location of soil boundaries
results:
Systematic random checks for
identification of soils
results:
location of soil boundaries
results:
Transect checks for
identification of soils
results:
location of soil boundaries
results:

VI. Narrative evaluation and other remarks

Table 1. A survey of 200 SRI's from all over the world.

Characteristics and Properties	Ultra-detailed	Meso-detailed	Macro-detailed	Meso-reconnaissance	Macro reconnaissance	Exploratory
1. properties						
a. Scale	>1:13,000	1:13,000–1:26,000	1:26,000–1:65,000	1:65,000–1:130,000	1:130,000–1:650,000	<1:650,000
b. Basic map units	Phases of consociations	Phases of consociations	Phases of consociations	Associations or consociations	Associations	Associations
c. Level of classification of map units	Soil series	Soil series or soil families	Soil families or subgroups	Subgroups or great groups	Great groups or suborders	Suborders or orders
d. Average-size delineation (cm^2)	12	4	5	6	6	5
e. Average-size delineation (ha)	9	20	130	680	5700	345,000
f. Minimum-size delineation (ha)	1	1–3	3–20	20–70	70–2,000	≥2,000
g. Index of minimum reduction	5	3	3	4	4	3
h. Map unit composition	U-L or U-S	U-L, U-S, some N-PS but more frequently some N-PL no X	U-L, U-S, some N-PS but more frequently some N-PL no X	U-L, U-S, some N-PS and N-PL some small areas of X	Mostly N-PS and N-PL some X	Mostly N-PS and N-PL some unknown
2. methodology of preparation						
a. Type of base map	Airphotos, orthophotos, topographic maps	Airphotos, aerial mosaics, orthophotos, topographic maps	Airphotos, aerial mosaics, topographic maps	Airphotos, aerial mosaics, topographic maps	Airphotos, aerial mosaics, planimetric maps	Airphotos, aerial mosaics, planimetric maps
b. Scale of base map	≥1:6,500	≥1:6,500–1:13,000	≥1:13,000–1:32,500	≥1:32,500–1:65,000	≥1:65,000–1:325,000	≥1:325,000
c. No. of reference points within circle –5cm^2, >1:20,000 –3cm^2, ≤1:20,000	Very high≥9 Low<2	Very high≥9 Low<2	Very high≥9 Low<2	Very high≥9 Low<2	Very high≥9 Low<2	Very high≥9 Low<2

Table 1. A survey of 200 SRI's from all over the world. (continued)

Characteristics and Properties	Ultra-detailed	Meso-detailed	Macro-detailed	Meso-reconnais-sance	Macro reconnais-sance	Exploratory
d. Approximate average no. of observations per km² (Vink, 1963)	100–500		1–3	±1	0.5–1	—
e. Plotting of soil boundaries continuously verified by						
1. visual observation	✓	✓				
2. verifed at closely spaced intervals			✓			
3. plotted by remote sensing with some verification				✓		
4. plotted by remote sensing					✓	✓
f. Type of analyses done for most profiles (check indicates necessity)						
1. routine	✓	✓	✓	✓	✓	✓
2. fertility-related and routine	✓	✓	✓			
3. special properties (salinity, acid sulfate etc.) and routine	✓	✓				
4. mineralogy and routine	✓	✓				
3. map interpretation potential						
a. indicates susceptibility of soils to deterioration	★★★	★★★	★★★	★★	★	
b. indicates suitability of soils for management and land preparation	★★★	★★★	★★	★	★	
c. indicates response to management	★★★	★★★	★★	★	★	
d. indicates constraints to land use	★★★	★★★	★★★	★★	★	

Table 1. A survey of 200 SRI's from all over the world. (continued)

Characteristics and Properties	Ultra-detailed	Meso-detailed	Macro-detailed	Meso-reconnais-sance	Macro reconnais-sance	Exploratory
4. ground-truth						
a. Soil map:						
1. internal composition or range in properties of map units	Very narrow	Very narrow	Narrow	Narrow	Broad	Very broad
2. map unit purity	85%	85%	85%	85%	60%	60%
b. Base map:						
3. density of ground control points	Moderate-high	High-very high	Moderate-high	Moderate	Moderate-low	Low
5. uses of soil map						
a. Master planning						
1. national planning				★	★★	★★★
2. regional planning			★	★★	★★★	★★★
3. cultural systems planning (generally by regions or large areas)			★★	★★★	★★★	★★
b. Project planning						
1. pilot projects for agricultural development	★★★	★★★	★★	★		
2. planning large-scale farm units	★★★	★★★	★★	★		
3. land settlement schemes	★	★★	★★	★★★	★★	★
c. Operational planning						
1. siting of experimental plots	★★★	★★	★			
2. siting drainage and irrigation systems	★★★	★★★	★★	★		
3. siting of buildings	★★★	★★★	★★	★		

Key: 1) U-S = uniform-suitable, U-L = uniform-limiting, N-PS = non-uniform predominantly suitable. N-PL = nonuniform-predominantly limiting, X = unknown. 2) ★ = minimum, ★★ = moderate, ★★★ = maximum.

Selection of a Method for Determination of Map Intensities of Soil Maps

M. C. Laker

The intensity of a soil map can be defined as the number of delineations demarcated per unit area. A large number of delineations per unit area indicates a high intensity.

Soil maps are published at different scales. Consequently, the number of delineations per unit area on different maps does not provide a true basis for the comparison of the intensities of different soil surveys. To obtain a true basis for comparison, intensity should be expressed as the number of delineations per unit actual land area (e.g., per ha or km^2).

The only way to determine the number of delineations per unit actual land area is by determining the number of delineations per unit area (e.g., per cm^2) on the published map and then calculating the number of delineations per unit actual land area. This calculation is done by means of a conversion factor, which is a function of the map scale.

The only direct and true way to determine the number of delineations per unit area on the published map would be by counting the total number of delineations in the whole map and dividing this by the total area of the map. This is such an extremely tedious procedure that it is completely impracticable.

The objective on this study was to find a method which provides a reliable measure of the actual number of delineations per unit area on a map and which is at the same time practicable.

PROCEDURE

Twelve map sheets, representative of published soil maps from different countries in Africa and Asia, were selected for the study. These maps were selected to provide examples of the different degrees of map intensity, different types of soil patterns, and different map scales that were encountered during a preliminary study.

A 15 cm × 15 cm square was drawn on transparent tracing paper. This square was fixed in position over one selected area of each of the map sheets. The total number of delineations in this 15 cm × 15 cm "mini-map" was then counted. The number of delineations per cm^2 was calculated for each "mini-map." This was the absolute figure for each "mini-map" and was used as the basis against which the different methods were then tested.

Six types of determinations were tested in each "mini-map." Three involved the use of a circle and the other three, the use of linear transects.

A circle with a radius of 2.5 cm (area: 19.64 cm², circumference 15.71 cm) was used for the circle counts. Preliminary studies indicated that a circle with a radius of 5 cm is too large and involves a counting procedure that is too tedious. The average number of delineations in a circle with a smaller radius is, on the other hand, considered to be too small to be a reliable measure. This was not tested statistically and was a purely arbitrary decision. Circle determinations were replicated at five different positions within each 15 cm × 15 cm "mini-map."

1. The first circle method involved the determination of the number of delineations within the circle. Each area in the circle was counted as a separate delineation. Even where two or more areas actually formed parts of one specific larger delineation which was mainly outside the circle, they were counted as different delineations. This is illustrated in Figure 1. Areas 1, 2, and 3 in the circle all

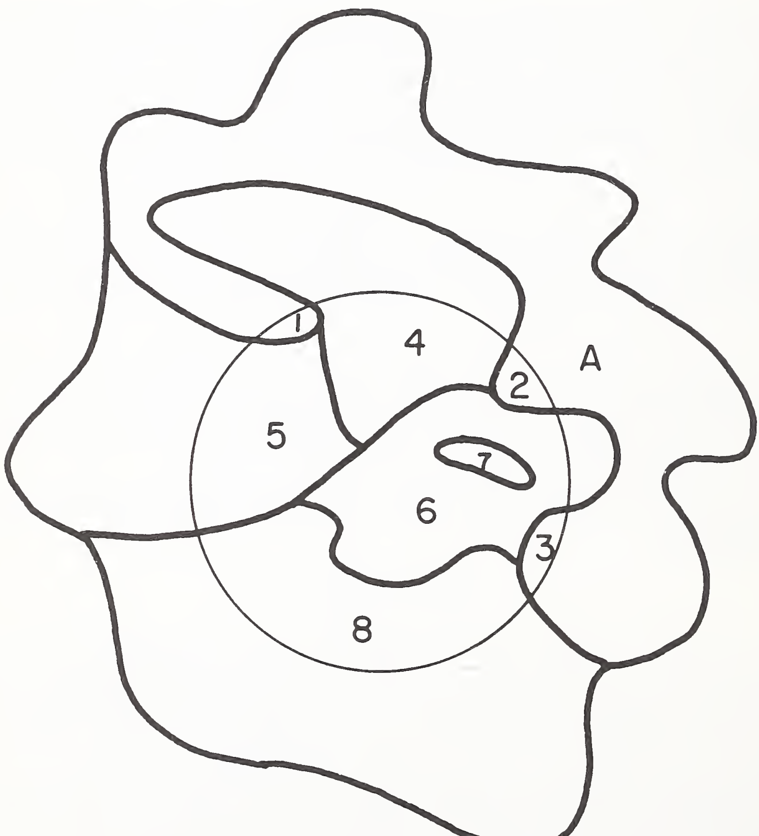


Figure 1. Illustration of the determination of the number of delineations in a 2.5 cm radius circle.

actually form part of the large delineation A. They are counted as three separate delineations, however, and the total number of delineations in the circle is taken as 8.

2. The second circle method also involved the determination of the number of delineations within the circle. However, where two or more areas actually formed parts of one large delineation they were counted as only one delineation. Thus, in the case illustrated in Figure 1, areas 1, 2, and 3 would be counted as only *one* because they all form part of one common delineation (A).
3. In the third case the number of lines crossing the circumference of the circle were counted. For the example illustrated in Figure 1 this would be 7.
4. The first linear transect determination consisted of counting the number of lines crossing a horizontal transect. Five transects, spaced at 3 cm intervals and spanning the total width of the 15 cm × 15 cm "mini-map," were studied in each case. The transects were spaced as illustrated in Figure 2 to ensure that all five transects were actually inside the "mini-map."

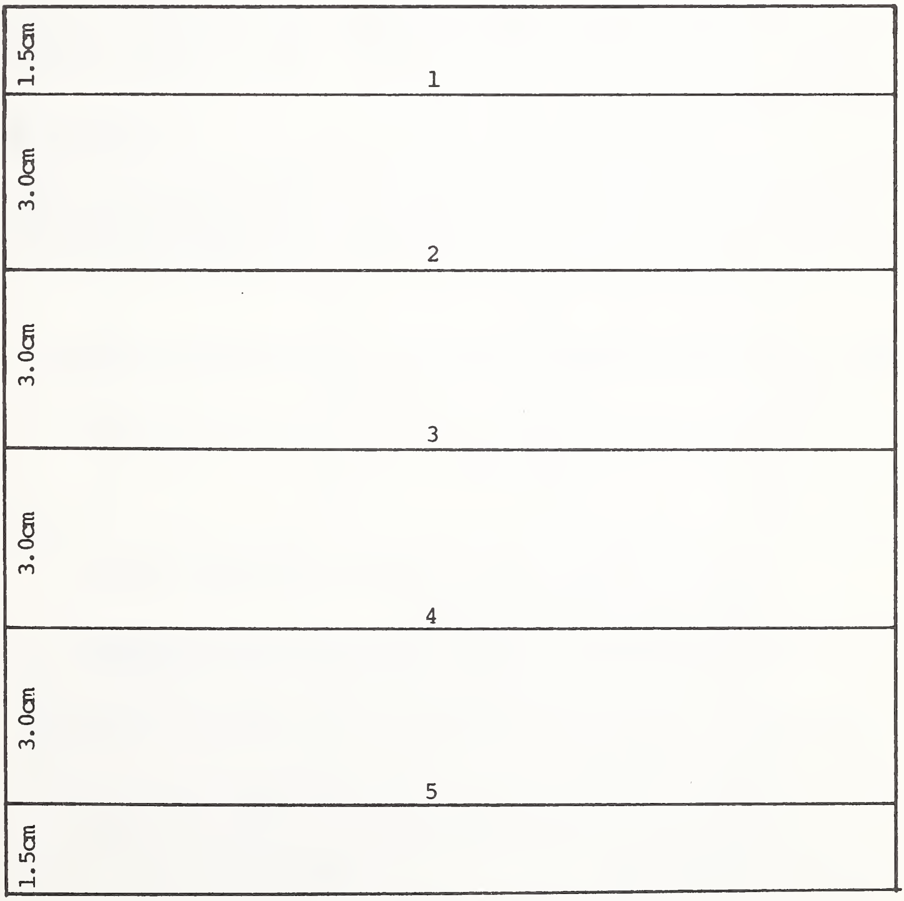


Figure 2. Illustration of positioning of 5 lines in a 15 cm × 15 cm square.

5. The second linear transect determination was similar to that described above, except that vertical transects were used instead of horizontal transects.
6. The third linear transect determination was just a calculation of the average of the horizontal and vertical transects combined.

In order to simplify subsequent tables, figures, and discussions, a set of symbols are defined in Table 1 for the different types of determinations.

RESULTS AND DISCUSSION

The average values for each of the types of determination for each of the twelve "mini-maps" are summarized in Table 2. The correlation coefficients for the relationships between the actual intensity (X) or its logarithmic transformation (X_1) or its square root (X_2) and the different methods tested to estimate X (i.e., Y_1 to Y_6) are given in Table 3.

From Table 3 it is clear that all six methods which were tested correlated very well with X or any of the two transformations of X which were used. Theoretically, any one of these six methods can be used to estimate the actual number of delineations per unit area in a soil map.

Some interesting observations can be made, however. Firstly, it is evident that the two methods which measure two-dimensional units (i.e., Y_1 and Y_2) provide an almost perfect method to determine the actual number of delineations per unit area (X). This is logical because the latter is also based on two-dimensional units (areas). The correlation coefficients for the relationships between Y_1 or Y_2 and the square root of X (X_2) are almost identical to the above. This is unexpected because, in this case, a

Table 1. List of methods employed to determine number of delineations per unit area.

Symbol	Parameter
X	Actual number of del/cm², determined in a 15 cm x 15 cm "mini-map"
X_1	1_n X
X_2	$\sqrt{X}$
Y_1	Representative number of del/cm², determined by counting the number of delineations in a 2.5 cm radius circle. Separate parts of the same delineation inside the circle are counted separately.
Y_2	Representative number of del/cm², determined by counting the number of delineations in a 2.5 cm radius circle. Separate parts of the same delineation inside the circle are counted together only as one.
Y_3	Number of lines/cm, determined by counting lines crossing the circumference of a 2.5 cm radius circle.
Y_4	Number of lines/cm, determined by counting lines crossing a 15 cm straight horizontal transect.
Y_5	Number of lines/cm, determined by counting lines crossing a 15 cm straight vertical transect.
Y_6	Number of lines/cm, average of Y_4 and Y_5.

Table 2. Results of measurements.

"Mini-Map" No.	Parameter						
	X^a	Y_1^a	Y_2^a	Y_3^b	Y_4^b	Y_5^b	Y_6^b
1	0.040	0.092	0.092	0.076	0.120	0.120	0.120
2	0.093	0.285	0.255	0.484	0.573	0.253	0.413
3	0.147	0.340	0.300	0.599	0.600	0.467	0.534
4	0.151	0.450	0.380	0.790	0.707	0.573	0.640
5	0.160	0.358	0.342	0.525	0.488	0.475	0.483
6	0.173	0.397	0.387	0.509	0.829	0.520	0.673
7	0.240	0.580	0.550	0.870	0.800	0.970	0.890
8	0.258	0.682	0.509	1.044	1.067	1.027	1.047
9	0.306	0.520	0.540	1.010	0.970	1.090	1.030
10	0.570	1.030	0.940	1.450	1.320	1.630	1.480
11	0.609	0.886	0.855	1.057	1.067	0.920	0.993
12	0.902	1.477	1.298	1.668	1.747	1.533	1.640

[a]Number of del/cm^2
[b]Number of lines/cm

Table 3. Correlation coefficients—All statistically significant at $P = 0.0001$; except $X:Y_5$, which is significant at $P = 0.0006$.

	X	X_1	X_2
Y_1	0.9736	0.9263	0.9719
Y_2	0.9866	0.9434	0.9883
Y_3	0.8970	0.9440	0.9369
Y_4	0.9114	0.9391	0.9403
Y_5	0.8432	0.9070	0.8948
Y_6	0.8930	0.9412	0.9350

two-dimensional unit is correlated with a linear or one-dimensional unit ($\sqrt{X}$). The graphs illustrating the linear relationships between Y_1 and X and Y_2 and X, respectively, are presented in Figures 3 and 4.

In the case of all the line transect countings, the logarithmic and square root transformations of X quite definitely improved the correlations with the different line countings (Y_3 to Y_6), although the effect was of no statistical significance. These improvements are logical since the one set of parameters (Y_3, Y_4, Y_5, or Y_6) in each determination was a linear function while the other (X) was a quadratic function (area). The direct linear correlations between Y_3, Y_4, Y_5, or Y_6 and X were actually much better than would be expected for the direct correlation between a linear function and a quadratic function.

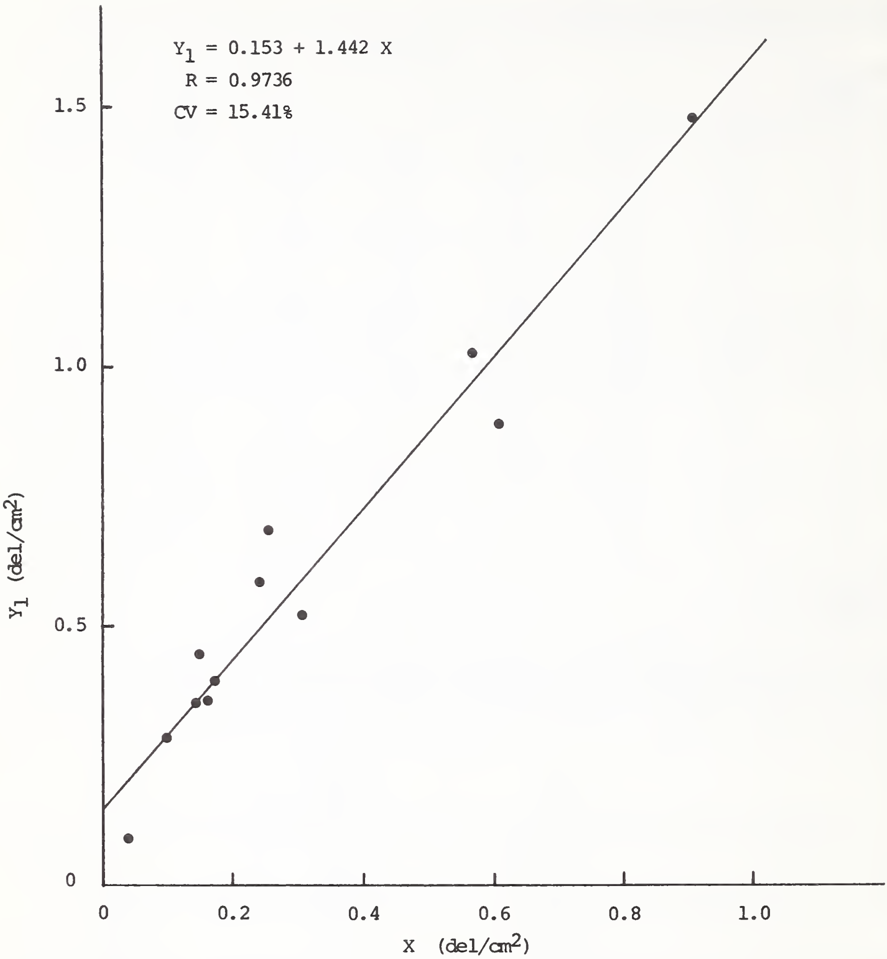


Figure 3. Relationship between X and Y_1.

The graph illustrating the best relationship between the circular line transect determinations (Y_3) and the actual number of delineations per unit area (X) is given in Figure 5. The graph for the average of the straight line transect determinations (Y_6) and X is presented in Figure 6. It is interesting that not only did both Y_3 and Y_6 correlate best with the logarithmic transformation of X, but the most important statistical parameters (the regression equations, R values and coefficients of variation) were also almost identical for the two graphs.

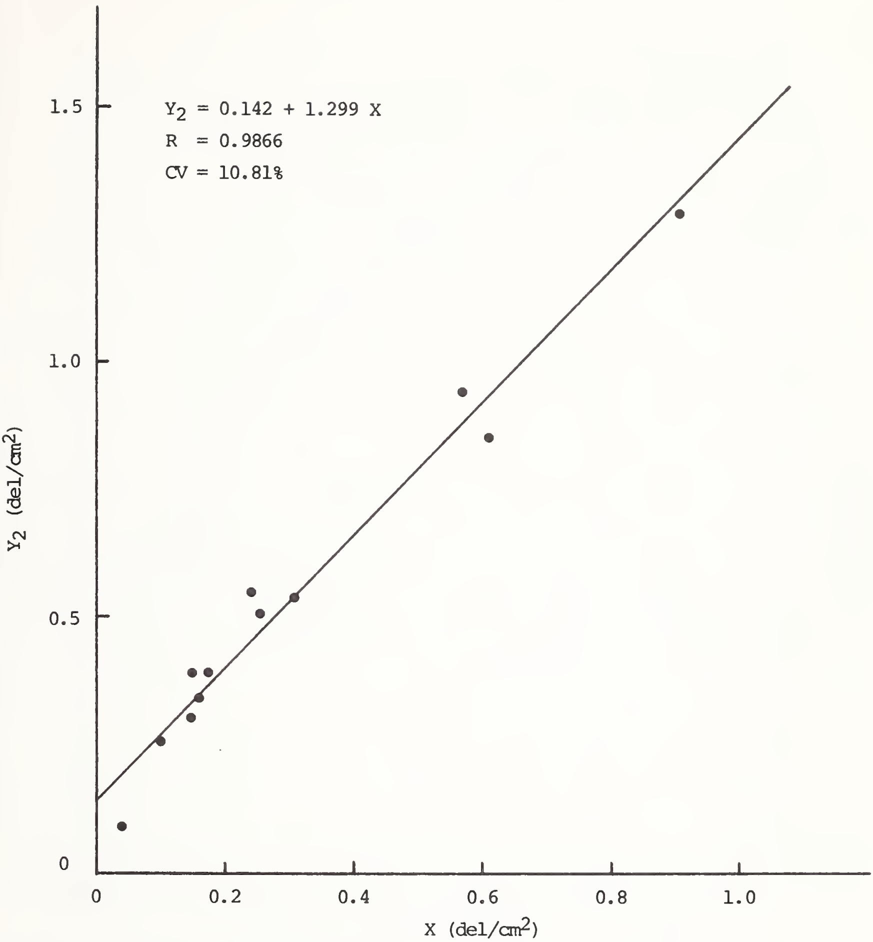


Figure 4. Relationship between X and Y_2.

SPECIAL TEST

Five replicates of each of the different types of determinations were made in a 10 cm × 10 cm "mini-map" on a part of a map sheet with an extremely high intensity and a very conspicuous "fibrous" type of soil pattern due to the presence of numerous small rivers. Estimated values for X were calculated using the regression equations given in Figures 3–6. These estimated values of X were also expressed as percentages of the actual directly determined value of X to get an indication of the accuracy of the different methods for this exceptional case. The results are summarized in Table 4. (Note: A 10 cm × 10 cm "mini-map" was used because a 15 cm × 15 cm one could not be fitted into the specific corner of the map sheet.)

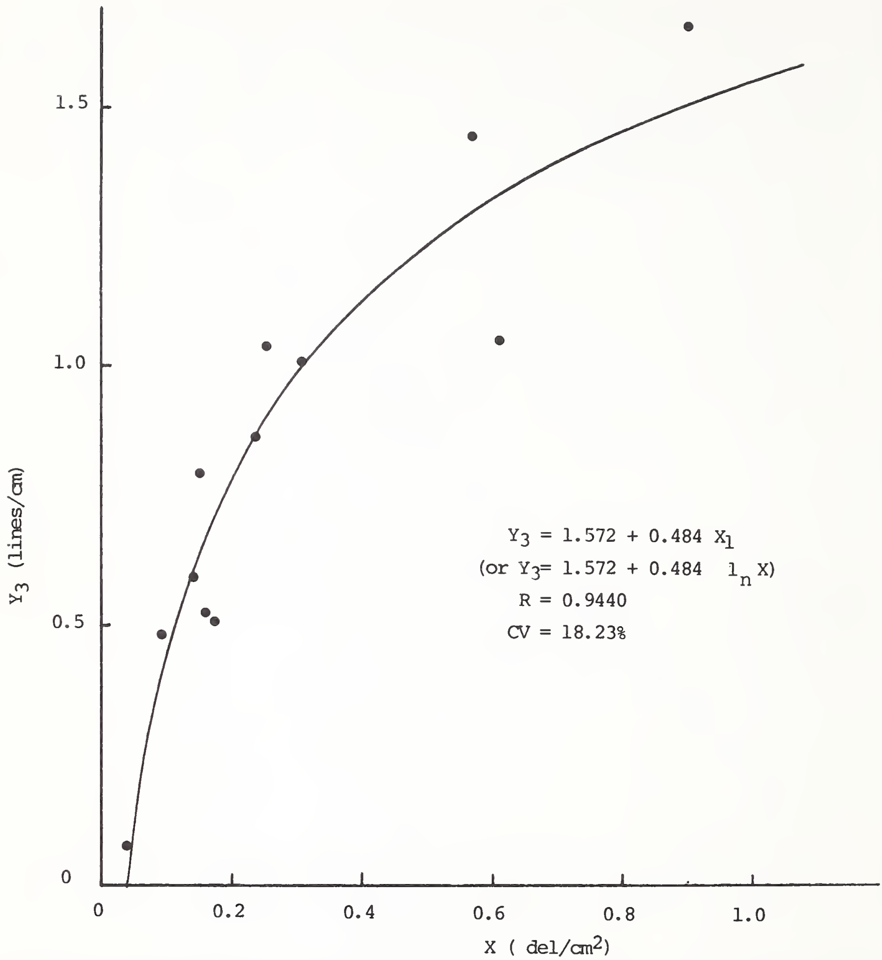


Figure 5. Relationship between X and Y_3.

From Table 4 it is evident that the two methods of counting the number of delineations in a circle gave very good estimates of the actual number of delineations per unit area despite these facts: the delineations had such exceptional patterns and a different size "mini-map" was used as reference.

Neither the circular line transect nor the straight line transect could give any indication of the actual map intensity for this type of map. In this case the linear regressions for these methods would actually give much better predictions for X, overestimating it "only" by 89 percent (Y_3) and 50 percent (Y_6), respectively.

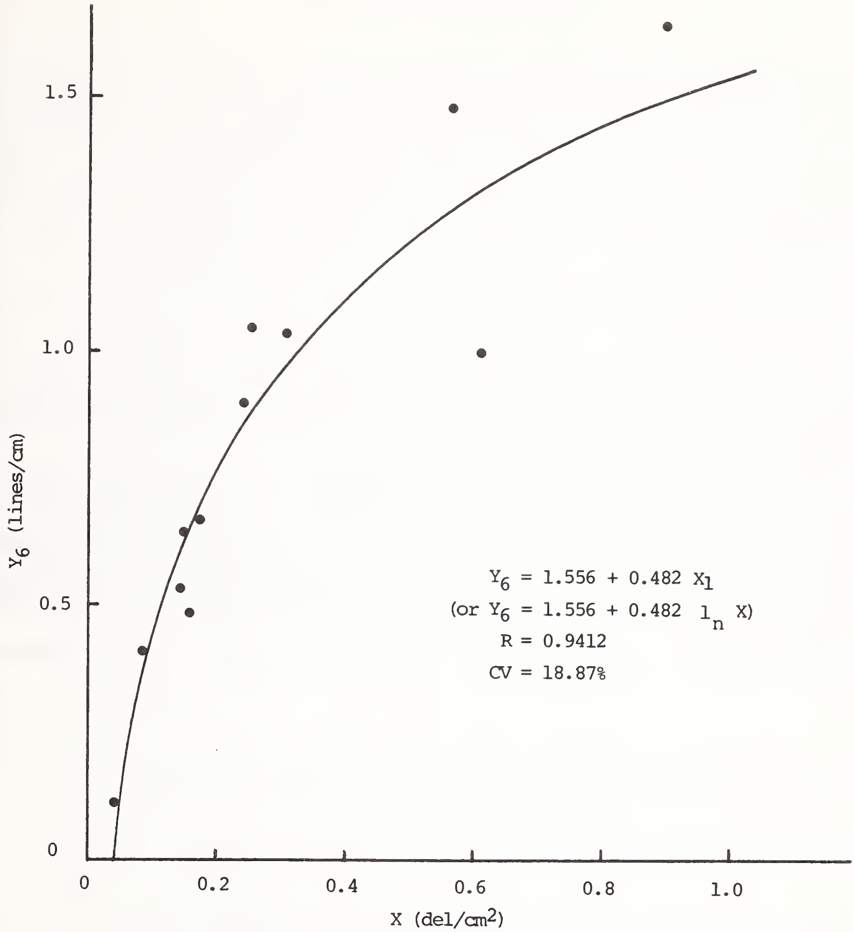


Figure 6. Relationship between X and Y_6.

Table 4. Relationships between actual map density and estimated map densities for a special type of map.

Method	Average Value	Xe[a] (del/cm^2)	$\frac{Xe}{X} \times 100$
X	1.09 del/cm^2	—	—
Y_1	1.92 del/cm^2	1.225	112.4%
Y_2	1.52 del/cm^2	1.061	97.3%
Y_3	3.56 del/cm	± 60	± 5500%
Y_6	2.86 del/cm	± 15	± 1400%

[a]Xe = X estimated by means of regression equations

RECOMMENDATIONS

In view of the results obtained for the correlation study, as substantiated by the special test, it is recommended that the number of delineations in a 2.5 cm radius circle are counted to calculate the actual number of delineations per unit area (or map intensity) for a soil map. It was found that it is easier to count every delineation that is encountered in the circle than to count those areas which form parts of the same larger delineation only once. Therefore, it is recommended that all delineations, or parts of delineations, in the circle are counted separately as they are encountered (Method Y_1).

It is recommended that ten random circle counts be made for each map sheet (or each intensity area in the case of multi-intensity maps) and that the average of these counts be used for further computations. To randomize the ten circle positions, the map sheet must be subdivided into a number of blocks of equal size. Useful block sizes range between approximately 100 cm^2 to 150 cm^2. Blocks demarcated by coordinate lines on the map or formed by the folding of the map can be used. These blocks are then numbered and ten blocks are selected randomly.

The circle counts are then made for each selected block in turn. The positioning of the circle in each block is done as follows: The circle (drawn on transparent paper) is held a few cm above the center of the block. It is then lowered onto the map sheet while looking away. The circle must not be shifted after it has been put down. These steps are intended to avoid conscious selection of certain map intensities or types of soil patterns.

The actual number of delineations per cm^2 on the soil map sheet is then calculated by means of Equation (1):

$$n = (0.0353\ AN - 0.106)\ \text{del/cm}^2 \tag{1}$$

Where n = actual number of delineations per cm^2 on the published map sheet, and

AN = average number of delineations per circle.

Equation (1) was derived by combining Equations (2) and (3).

Equation (2) gives the average number of delineations per cm^2 in the circles:

$$y = \frac{AN}{19.64}\ \text{del/cm}^2$$

Where y = the average number of delineations per cm^2 in the circles,

AN = the average number of delineations per circle, and

19.64 = the area of a circle with a radius of 2.5 cm (in cm^2).

Equation (3) is the regression equation which gives the relationship between the average number of delineations per cm^2 in the circles and the actual average number of delineations per cm^2 on the map:

$$n = (0.693y - 0.106)\ \text{del/cm}^2 \tag{3}$$

Where n and y are as in Equations (1) and (2). (This equation is another form of the equation given in Figure 3.)

Equation (1) is obtained by substitution of Equation (2) into Equation (3):

$$n = (0.693y - 0.106) \text{ del/cm}^2 \tag{3}$$

$$\text{but } y = \frac{AN}{19.64} \text{ del/cm}^2 \tag{2}$$

$$\text{therefore, } n = (0.693 \frac{AN}{19.64} - 0.106) \text{ del/cm}^2$$

$$\text{thus } n = (0.0353\ AN - 0.106) \text{ del/cm}^2 \tag{1}$$

Piech (personal communication) tested the validity of this method for an actual average size map sheet (instead of a "mini-map," as was used in the development of the method). By counting all the delineations on the whole map sheet, she found an average of 0.424 del/cm^2. By using the recommended circle method and Equation (1) she found an average of 0.448 del/cm^2. This represents a difference of only 5.7 percent.

The average number of delineations per cm^2 in the circle (y) may never be used instead of n as a shortcut, because this will give completely incorrect results. In the example tested by Piech (personal communication) y was 0.80 del/cm^2, which over-estimated the actual number of delineations per cm^2 on the map by almost 89 percent.

Equation (1) can only be used if the following conditions are observed:

1. A circle with a 2.5 cm radius must be used. Circles with other radii will require other equations.
2. The number of delineations must be counted according to method Y_1.
3. Results must be expressed in terms of delineations per cm^2 on the published map.
4. AN must not be lower than 5.75 delineations per circle (y must not be lower than 0.300 del/cm^2). In other words, Equation (1) is not valid for maps with very low map intensities. This is because the size of the circle becomes a limiting factor on maps with such large delineations.

If AN is smaller than 5.75 delineations per circle, then Equation (4) is used to calculate n:

$$n = (0.0299\ AN + 0.164)^2 \tag{4}$$

Equation (4) is based on the regression equation describing the quadratic relationship between n and y (i.e. the relationship between X_2 and Y_1, see Tables 1 and 3).

In the case of maps with extremely low map intensities, i.e. where AN is smaller than 2.00 delineations per circle (y is smaller than 0.100 del/cm^2), it will be more correct and easy to count the actual number of delineations on the whole map rather than to use the indirect circle method.

Applications of *n*

All other parameters related to map intensities are calculated using n as the basis. These parameters include (i) average-delineation, (ii) map texture intensity, (iii) map index of maximum reduction, and (iv) minimum scale of reduction. These were discussed by Eswaran, Forbes, and Laker (this volume).

Soil Map Parameters and Classification

H. Eswaran, T. R. Forbes, and M. C. Laker

The concept of soil map evaluation implies to most people an assessment of (1) the accuracy and thoroughness with which different soil areas are indicated, and (2) how useful the map is for planning and decision-making purposes. However, many users of soil maps may not be able to check the accuracy of the map (ground truth). They may be quite familiar with other physical attributes of the area in question such as the climate, geology, relief, etc., but not necessarily familiar with the distribution of soils of the area. Such a user may gain much information simply by examining the "information content" of a soil map. By "information content" is meant the relationships found in the number, size, shape, frequency, and pattern of soil areas or delineations outlined on a soil map; soil variability; and map legend characteristics.

This section discusses measures which have been developed to appraise the characteristics of the soil map itself. Such attributes as the number, size, shape, and pattern of soil areas outlined on soil maps are dealt with. These affect legibility and are indicators of the amount of detail mappers have shown in relation to map scale. They do not pertain directly to the accuracy of the information presented. Several concepts have been developed concerning the attributes of delineations on maps and these will be set forth here. These concepts of map attributes form the basis of a methodology of map evaluation and map classification.

CHARACTERISTICS USED FOR SOIL MAP EVALUATION AND CLASSIFICATION

Map legibility

Legibility refers to the ease with which a map user can read the information recorded on a soil map. A legible map presents information in a direct, clear, concise, and perhaps pleasing or artistic manner. Several factors influence the legibility or readability of a map:

1. the number of outlined soil areas, called delineations, per unit area of the map (i.e. the sizes of delineations).
2. the choice of colors or patterns to represent delineations.
3. ground control (cultural and natural features shown to allow readers to locate soil areas on the ground) or amount of non-soil features (vegetation or land use) included in the map.
4. quality of map presentation.

Too many delineations crowded into a small area make a map illegible or difficult to use. Delineations which are too small to be easily identified detract from legibility.

In colored maps, choice of colors is critical. The "Scottish-plaid" maps, where cross-hatching with different colors is employed, are unsightly and may be confusing. Colors which are too dark may obliterate a lot of ground control detail or important non-soil features.

Indications of ground control features are essential to locate soil areas. An insufficient amount of ground control may make a map unusable. A map crammed with ground control and overloaded with non-soil information obscures soil information.

Finally, legibility is also a function of the printing quality, i.e. quality of the paper, quality of the print, lay-out, and many other factors which make for good, clear graphic representation.

Study of the factors affecting legibility led to the development of a number of measures which proved to be useful in the description and evaluation of a large and varied sample of soil maps. They should be useful for evaluation of most soil maps. These are discussed and, where appropriate, examples are given.

Minimum-size delineation

The "minimum-size delineation" is a term found in the existing literature on soil maps (USDA, 1975). The minimum-size delineation appears to be equivalent to Vink's (1963) "basic mapping unit." Vink described it as "the smallest area that still can be indicated on a map" (Vink, 1963). It might be helpful to add to Vink's definition "the smallest area that still can be *legibly* indicated on a map." In this respect the minimum-size delineation is purely a cartographic parameter.

According to the USDA (1977) and Smyth (1970) the legibility of a map decreases greatly if a large number of map symbols must be placed outside small delineations and keyed into them by arrows. In this regard a minimum-size delineation can be defined as the smallest delineation in which a simple map symbol (consisting of no more than two or three digits) can still be printed legibly. In this regard the shape of a delineation is important, i.e. a long, thin delineation must be relatively large, as compared to a round or square delineation, before it is possible to print a symbol in it. The criterion of being able to print a simple map symbol in a delineation requires a larger minimum-size delineation than the criterion of simply being able to demarcate a soil boundary.

Obviously the smallest legible delineation is, within certain size limits, quite an arbitrary or subjective concept. The minimum-size delineation then has the following attributes:

1. It is the smallest delineation inside which a simple map unit symbol can be printed legibly, or
2. It is the smallest area which can be easily discerned by a user of a map, and
3. It is actually determined by which one of (1) or (2) is the larger one.

The minimum-size delineation is a "constant" for the determination of a suitable published scale and also is a constant for the comparison of the other map parameters which are discussed henceforth. For purposes of uniformity it was decided to assign an arbitrary value of 0.4 cm^2 for the area of the minimum-size delineation. This area seems to fall in the range of areas which for the most people delimit the boundary of legibility of the most frequently occurring smallest areas on soil maps. The USDA (1975) considers the minimum-size delineation to have an area of ¼ × ¼ inch or 1/16 $inch^2$ or

0.403 cm². Vink (1963) indicates his "basic mapping unit" by 0.5 cm × 0.5 cm or 0.25 cm². Figure 1 illustrates minimum-size delineations which, when the original scale of the map is reduced, become illegible and inaccurate.

The actual land area which is equivalent to 0.4 cm² on a map is a function of the map scale. The values for a series of map scales are given in Table 1.

Least-size delineation

On examination of many soil maps one will often find that there are some delineations smaller than 0.4 cm². These have been named least-size delineations and are defined as

Figure 1. The arrow indicates a minimum-size delineation which becomes less legible as the original map (A) is successively reduced (B–D).

Table 1. Minimum-size delineation values on actual ground scale for a number of map scales (minimum-size delineations for all published maps being 0.4 cm²).

Map Scale	Minimum-size delineations on ground scale (ha)
1:5,000,000	100,750
1:1,000,000	4,030
1: 500,000	1,008
1: 250,000	252
1: 200,000	161
1: 100,000	40.3
1: 50,000	10.1
1: 25,000	2.52
1: 20,000	1.61
1: 10,000	0.40

the smallest areas which are actually delineated on a specific map by a soil surveyor. If only a few of these very small delineations are found on a map, then they do not decrease legibility of the entire map under examination.

The least-size delineation may be an indication of the amount of detail the surveyor attempted to include in parts of the map or may be an indication of the variability of the soils of the area or it may be just a purely incidental observation. The latter is especially true for small scale maps.

It was observed that least-size delineations are normally smaller than the theoretical minimum-size delineations, are usually oval in shape, and are usually found as small "islands" within larger delineations. Least-size delineations are particularly significant in large scale maps, since this would seem to imply highly contrasting small areas that are not just incidental observations. Figure 2 shows some examples of selected map areas with least-size delineations. Note that the areas do not meet the requirements of legibility as do the minimum-size delineations.

Average-size delineations

The size of delineations on a soil map is determined by the complexity of the soil pattern, the way in which mapping units are defined, and the map scale. The attributes of complexity of soil patterns can be assessed through soil contrast and variability. The efficiency of the surveyor and design of the legend will determine whether or not the necessary attributes of contrast and variability are sufficiently defined on the map by the delineations for the specified purpose(s). If then contrast and variability are optimally represented, the size of delineations should reflect these aspects and therefore this size of delineations is an important attribute of soil maps.

The average size of the delineations on a soil map is termed the "average-size delineation." The average-size delineation can be expressed in terms of the average number of delineations per unit area on the map. The average-size delineations can be converted to some appropriate unit (e.g., ha or km²) on actual ground scale.

Mapping intensity

Some parts of soil survey project areas may be mapped more intensively than others. As a result some parts of the soil map have more delineations per unit area than others (see Figure 3). The larger delineations of the less intensively surveyed area may

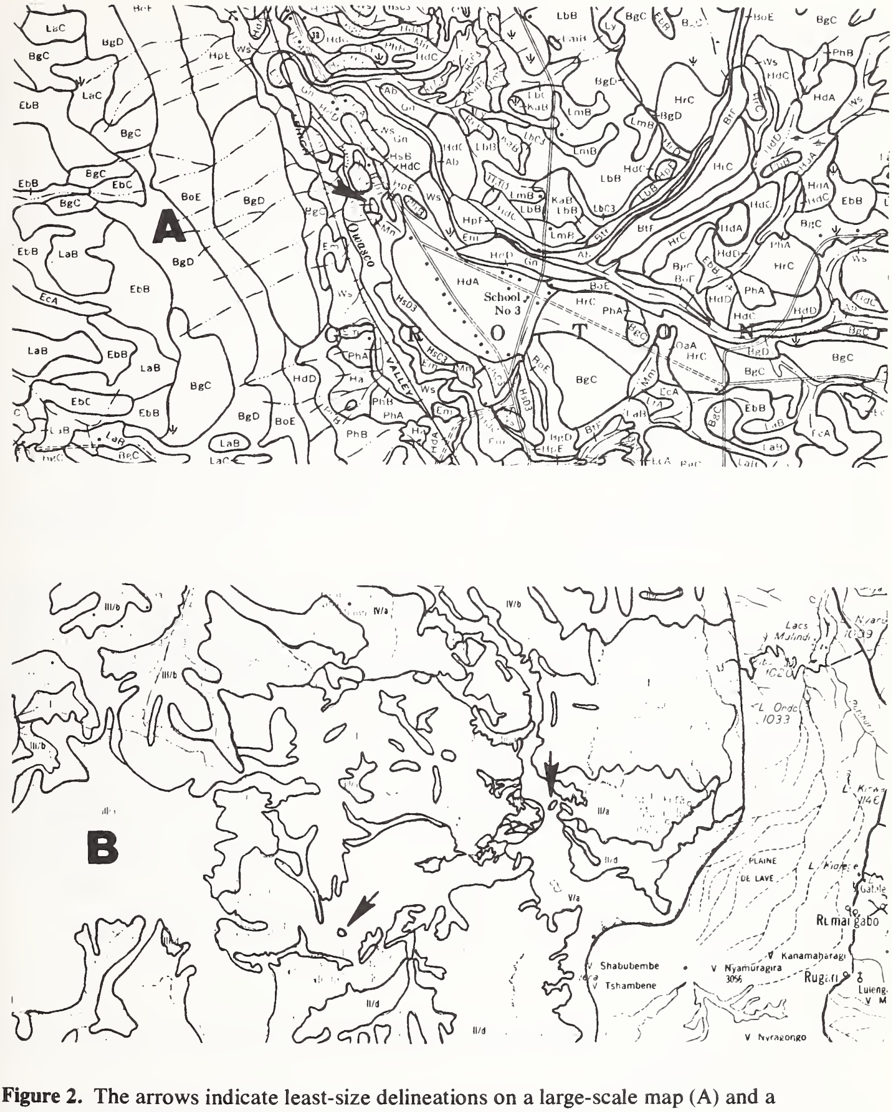


Figure 2. The arrows indicate least-size delineations on a large-scale map (A) and a small-scale map (B).

correctly represent associations or higher levels of generalization. The more intensively surveyed areas may be represented by map units of lower taxonomic classes. The reasons for mapping at two or more intensities in different parts of a survey area include the following:

Objectives of the survey. For surveys with specific objectives the areas where the objectives are feasible (or are likely to be feasible) may be mapped at greater intensities, for example:

Figure 3. This map reproduction shows two adjacent land areas mapped at different intensities.

1. When the objective is to locate soils for wet-land padi, adjacent hilly areas may receive less attention.
2. When national laws prohibit cultivation above certain elevations, these areas may not be traversed at all.

Physical limitations, such as accessibility. Jungle and swamps are commonly not mapped at the same intensity as adjoining cleared areas, unless specific objectives require them and warrant the extra cost.

Soil heterogeneity. When all other factors are constant, map intensity is determined by the complexity of the soil patterns. Areas which are characterized by large homogeneous tracts of soil of low contrast and variability have a low map intensity. However, in this case it does not mean that the low intensity areas were mapped less accurately.

Nature of the legend. This should not affect intensity but there is a general tendency to have more subdivisions for soils with aquic soil moisture regimes or those formed over alluvium than for the well-drained upland soils.

Soil maps can be divided into those which have only one intensity over the whole map or are uniform (so-called mono-intensity maps) and those that reflect different intensities on different parts of the map (multi-intensity maps). These intensities are defined purely in terms of complexity of the map. They may or may not indicate different mapping intensities. There are different ways to determine whether a soil map is a mono- or multi-intensity map. The most common are:

1. Indications in the accompanying soil survey report that different areas were mapped at different intensities.
2. *Visual estimation.* A map may be divided into two or more parts by visually estimating the mapping intensities.
3. *Stratified sampling.* This may be used to confirm visual observations and to define boundaries between areas of different intensities.
4. *Random sampling.* This may be used to confirm visual observations in a more general way. Boundaries are not as precise as those defined by stratified sampling or by circle counts. (See "Selection of a Method for Determination of Map Intensities of Soil Maps" by M. C. Laker, this volume.)

Map texture and map texture intensity

Map texture refers to the sizes and distribution of the delineations on a map as a whole or on parts of it, depending on whether it is a mono- or multi-intensity map. In multi-intensity maps, the map textures in the different intensities are described separately.

The maximum possible number of delineations per cm^2 is determined by cartographic limitations and is the reciprocal of the minimum-size delineation. Since the minimum-size delineation has been set at 0.4 cm^2, the maximum number of delineations is 2.5. The map texture intensity is defined as the ratio of the observed number of delineations per cm^2 (n) to 2.5.

$$\text{Map texture intensity} = \frac{n}{2.5}$$

$$\text{Since } n = \frac{1}{\text{average-size delineation}}$$

$$\text{and } 2.5 = \frac{1}{\text{minimum-size delineation}}$$

$$\text{therefore also map texture intensity} = \frac{\text{minimum-size delineation}}{\text{average-size delineation}}$$

The map texture intensity is an index of complexity or simplicity of the map, using the maximum number of delineations as a base. For comparison of portions of a map or of different maps, the map texture intensity is expressed in a percentage by multiplying by 100.

Both map texture and map texture intensity can be used as clues to suggest relative mapping intensities, although they may reflect differences in soil pattern in nature as well. They provide comparative data by means of which mapping intensities within the confines of a specific map scale can be compared. This is of practical importance, as will be indicated. They also provide the basic data by means of which actual mapping intensities can be calculated.

Map index of maximum reduction

A map becomes illegible if a large proportion of the delineations are very small. If most of the delineations are very large, then the map is of good cartographic quality and highly legible, but this does not mean that it is a "good" map.

The map index of maximum reduction is defined as the degree to which scale of a map can be reduced before the average-size delineations become smaller than the theoretical minimum-size delineations (which are taken as 0.4 cm^2). It is therefore postulated that the scale of a map can only be reduced until the average-size delineations of the reduced map become equal to the minimum-size delineations. The map index of maximum reduction is therefore defined as the square root of the ratio between the average-size delineation and minimum-size delineation of the actual published map.

$$\text{index of maximum reduction} = \sqrt{\frac{\text{average-size delineation}}{\text{minimum-size delineation}}}$$

Thus, map intensity can also be specified by the map index of maximum reduction where the map index of maximum reduction is inversely proportional to the square root of the map texture intensity.

In multi-intensity maps, the map index of maximum reduction, for purposes of classification, is determined by the portion which has the smallest average-size delineations, i.e. by the portion which has the finest texture. The map index of maximum reduction, however, could be determined for all portions of the map.

Minimum scale of reduction

The minimum scale of reduction is the smallest scale to which a map can be reduced before the sizes of average-size delineations become smaller than the minimum-size delineation limit. The minimum is the product of the actual published map scale and the map index of maximum reduction:

$$\text{minimum scale of reduction} = \text{actual map scale x index of maximum reduction}$$

For example, suppose actual map scale = 50,000 (for a map scale of 1:50,000) and map index of maximum reduction = 2. Then minimum scale of reduction = 50,000 × 2, or 100,000.

The minimum scale of reduction does not indicate a useful map scale. If the average-size delineations are reduced to the size of minimum-size delineations, it will be clearly seen that a large proportion of the delineations will be so small that the actual utility of a map at this reduced scale will be extremely low.

The map index of maximum reduction and minimum scale of reduction are parameters which could be used to evaluate the quality of a map. If the map index of maximum

reduction is low, i.e. 1–2, the map or parts of the map are intensively mapped. On the other hand, if it is 10–20, the delineations are very large. This may indicate: (1) homogeneous soil units in nature, (2) improper scale definition in terms of legend (perhaps an example of this may be the use of soil associations at a scale larger than necessary), or (3) a poor survey. It also implies that the surveyor could have worked with a smaller scale.

Figure 4 relates the actual map scale and map index of maximum reduction to the minimum scale of reduction.

BOUNDARY REPRESENTATION, MAP SCALE, AND SIZES OF DELINEATIONS

To relate delineation boundaries, map scale, and delineation sizes, some background information must first be introduced.

The intensity of survey and map scale influence the reliability of boundary location. At large scales a large number of observations are required for boundary placement and the actual position of the boundary is theoretically more certain than at smaller scales. Also the amount of significant or critical ground control data that aids in the location of soil boundaries decreases rapidly as the scale of the base map decreases.

Arnold (personal communication) states: "The accuracy of map boundaries involves locational tolerances and the width of line relative to scale of map being evaluated. Because many soil boundaries are related to transitional or gradational sets of soil properties that are not easily recognized by external features, there is a zone of acceptable placement of such soil boundaries due to the judgment involved. The width of a pencil line or a standard pen represents different ground widths according to the scale of the map. For instance, a Koh-I-Noor No. 0 pen line is 0.016 inch and represents 34 ground feet at 1:24,000 and about 708 feet at 1:500,000 (Hord and Brooner, 1976)."

Line thickness

The thickness of the lines which are used on the final map is important. Normally lines that are 0.3 mm or 0.4 mm wide are used, but lines as wide as 1.0 mm have been found, even on published maps. According to Arnold (personal communication), the National Map Accuracy Standard of the U.S. indicates that for an accurate map at a scale of 1:20,000 or smaller, not more than 10% of well-defined points shall be in error by more than 1/50 inch (i.e. 0.02 inch or 0.5 mm).

The thickness of map delineation lines therefore can have an effect on the percentage error which the standard delineations, minimum-size and average-size discussed previously, contain. A factor to consider is the magnitude of boundary errors caused by the thickness of map delineation lines. As was indicated by Arnold (personal communication) a line of 0.4 mm represents a ground width of only about 212 meters on a scale of 1:500,000 or a width of about 10 meters on a scale of 1:24,000. The three meters or less which it represents at a scale of 1:6,000 may not at first appear to be significant.

Delineation purity in relation to boundary error

The magnitudes of these "small" errors relative to the sizes of delineations present a completely different picture, however. Suppose (hypothetically) that all delineations are circles. Suppose there are three delineations with sizes of (a) 0.4 cm^2, (b) 1.131 cm^2, and (c) 19.64 cm^2 respectively. Delineation (a) is the size of the defined minimum-size

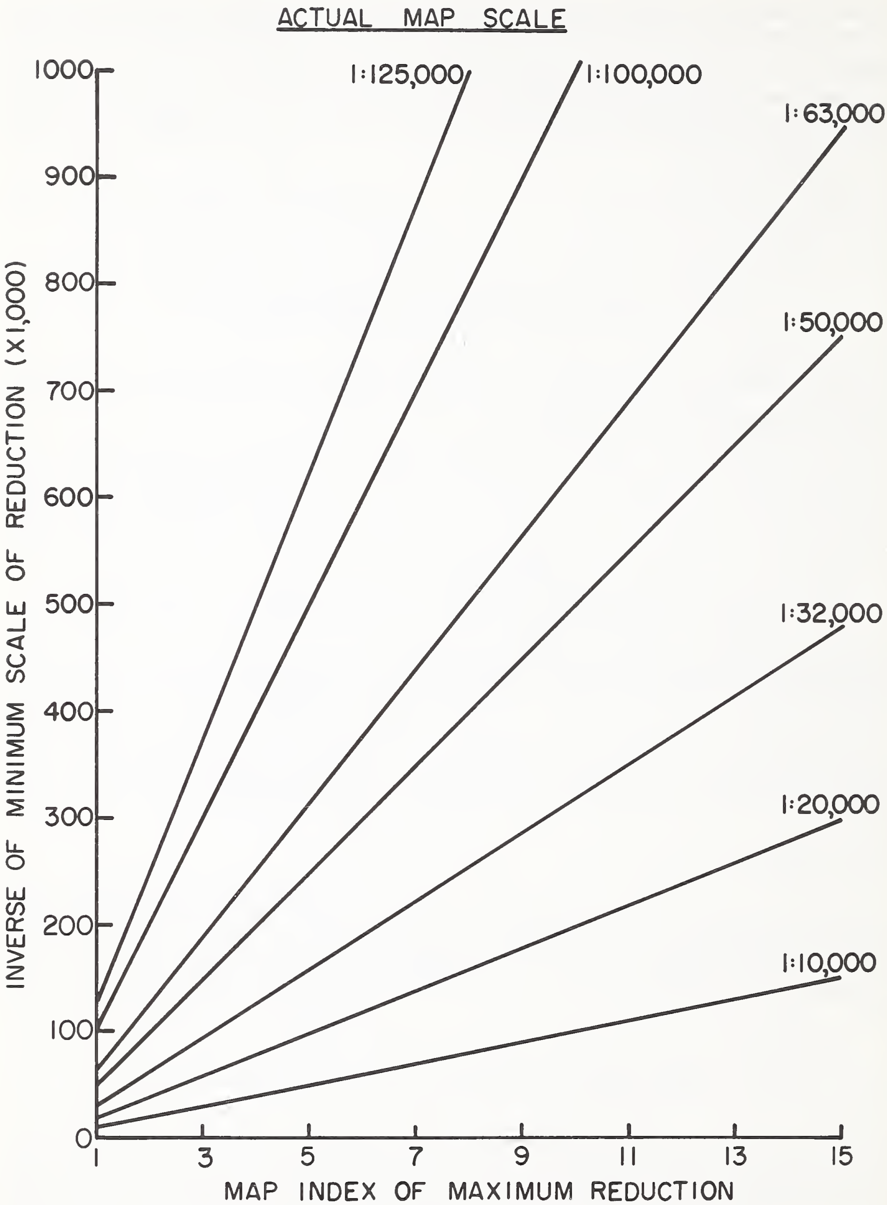


Figure 4. Relationships between actual map scale, map index of maximum reduction, and minimum scale of reduction.

delineation. The reason for the choice of size (b) will be explained later. Size (c) represents the area of the circle which is used for the determination of the average-size delineations.

Suppose the radii of the circles are (1) either 0.3 mm too small or 0.3 mm too large, or (2) either 1 mm too small or 1 mm too large. The percentage errors for each of the three delineations for each of the two cases are summarized in Table 2, which clearly illustrates how the percentage error increases with decreasing delineation size. This increase is curvilinear, because of the quadratic relationship between area and radius (Figure 5).

For shapes other than true circles this relationship between linear error and error in area will follow the same quadratic type of pattern.

Secondly, the percentage error in delineation size increases linearly as the linear boundary placement error increases, for a specific delineation size. The rate of increase in error in delineation size with increasing boundary error is much larger for small delineations than for larger delineations (Figure 6). This means that relatively small increases in boundary error have much more serious consequences in the case of small delineations than in the case of larger delineations.

Useful delineation sizes

Overall there is a great degree of parallelism between the degree of boundary precision that is required for different levels of planning detail and the degree of boundary precision that can be attained at corresponding map scales. It may therefore be logical to have a constant, basic delineation size for each range of map scales that are encountered. These delineation sizes must be large enough so that errors due to incorrect boundary placement are small enough to be acceptable. The U.S.D.A. (1977) indicates that an absolute maximum of 10 percent of a limiting inclusion is the most that can be tolerated in a mapping unit of an ultra-detailed soil map.

One can then relate this criterion to boundary errors and their effect on percent limiting inclusions. If we accept that a boundary can be in error by 0.3 mm on a detailed soil map, then it is found that a delineation may not be smaller than 1.131 cm^2 to be in error by no more than 10 percent (Table 2). It can actually be expected that boundary errors are larger than this. This would require an even larger delineation to be acceptable. A round figure of 1.2 cm^2 can be used to indicate the minimum reliable delineation size. For a boundary error of 0.3 mm, a delineation size of 1.20 cm^2 not only approaches the critical acceptable level of 10 percent error, but also represents an

Table 2. Magnitudes of error in sizes of delineations if the radii of delineations are in error by different degrees.

Correct Size of delineation (cm^2)	Percentage error in sizes of delineations: Radius in error by 0.3 mm	Radius in error by 1 mm
0.400	16.9	56.1
1.131	10.0	33.4
19.64	2.4	8.0

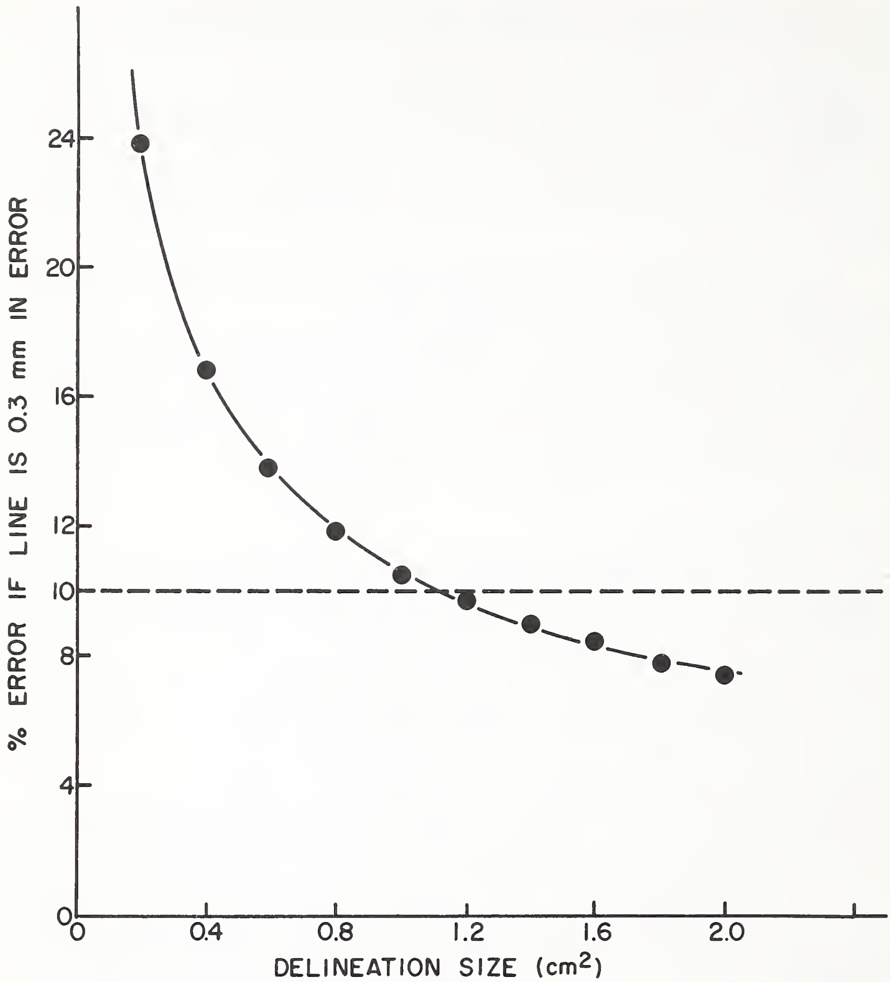


Figure 5. Percent error of delineation content as a function of delineation size.

important turning point on the curve (Figure 5) relating percentage error to delineation size. For delineation sizes above 1.20 cm^2 the decrease in error relative to increase in delineation size

$$\left[-\frac{\Delta E}{\Delta S}\right]$$

becomes low. In other words, gains in accuracy by having larger delineations become low above this value. Below this value drastic losses in reliability with decreasing delineation size is operative, however.

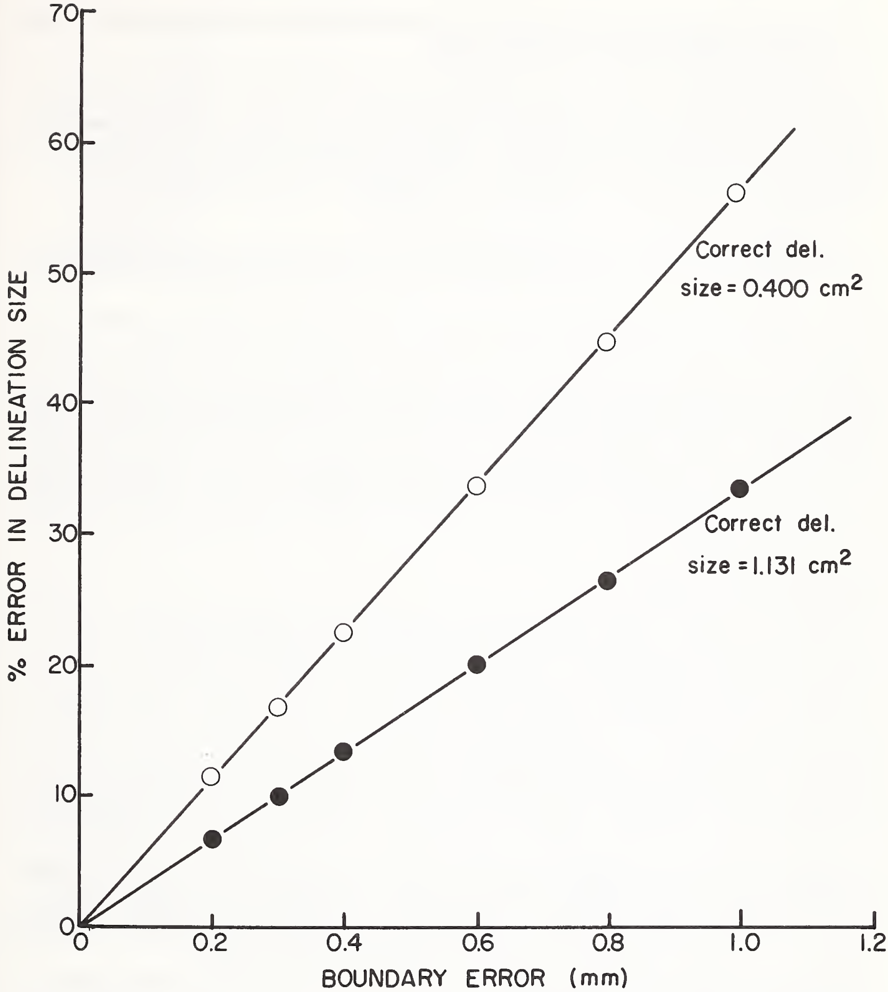


Figure 6. Percent error in delineation content as a function of boundary error.

This delineation area is a cartographic property, much as the minimum-size delineation was, and is 1.2 cm² no matter what the actual map scale.

A decision about map scale can then be made according to the following criteria:

1. For what purpose is the survey to be used?
2. With what degree of precision can boundaries normally be expected to be located on maps of the scale range which is normally used for that purpose?
3. What maximum percentage of delineation error is permissible?
4. What is the minimum-size delineation that will still have an acceptable small error at the degree of boundary precision which is expected?

5. At what map scale will the minimum area of interest to planners be equal to this minimum acceptable delineation size?

It is logical that for a map to be useful the average-size delineations should not be smaller than the minimum acceptable delineation size. Even if the average-size delineations are equal to the minimum acceptable delineation size the map will have too many small delineations to be useful for the originally intended purpose.

CLASSIFICATION OF MAPS BASED ON MAP CHARACTERISTICS

Several map characteristics may be used to classify maps. The most convenient of these is the actual scale of the map. Map scales are expected to give an indication of the possible uses of the map, the level of detail incorporated in it, and the kinds of interpretations that could be made. Unfortunately, map scales are not sufficiently informative apart from allowing a map user to convert map areas to land areas. Soil surveys differ in their philosophy, methodology, and manner of presentation of data and all these factors make it difficult to judge the quality of maps or to use the scale alone for classifying maps.

Density of observations

Vink (1963), developing on an earlier suggestion of Buringh, introduced the concept of the "basic mapping unit." He suggested that each map should carry a square or rectangle representing an area of 0.25 cm^2 on the map. The square or rectangle represents at least one observation and if the number of observations varied, the size of the square or rectangle was changed proportionately. Steur (1961), Vink (1963), and Boulaine (1966) all believe that the density of observations provide a better measure of detail than map scale. It is partly for this reason that Vink (1963) wished to have some indication of density of observation on soil maps. The actual map scale together with the density of observations provide some measure of the reliability of the map. This measure could then be employed as a parameter in the classification of maps. However, the proposal is not tenable as it only applies for grid surveys (as defined by Steur, 1961). In addition, many soil survey reports do not give information on the density of observation and so this parameter cannot be used to classify maps.

However, Boulaine (1966) and Burrough, Beckett, and Jarvis (1971) employ the density of observations to define their "virtual scale" (the scale of the map recalculated to give five observations per cm^2). They indicate that this is only applicable to grid surveys. In developing the concept of the virtual scale, they imply that the actual scale of the map must be accompanied by some other parameter which defines the survey methodology or results, in order for maps to be compared or classified.

For convenience, and in the absence of other universal parameters, the actual map scales are employed to develop classes in the *Soil Survey Manual* (U.S.D.A., Soil Conservation Service, 1977, in preparation). Six classes are recognized, but the class limits proposed do not include the map scales most frequently used within a class. Therefore some changes are needed. In Table 3, the class limits of the *Soil Survey Manual* and the modified limits are given. The modifications are based on a proposal by Cline (1977, this volume).

In the following proposal for classification of maps, the limits of the modified map scales in Table 1 will be used; the class names will be retained.

Table 3. Map classes as a function of map scales.

Classes	Map scales	Modified map scales
A. Ultradetailed	>1:7,920	>1:13,000
B. Mesodetailed	1: 7,920–1: 24,000	1: 13,000–1: 26,000
C. Macrodetailed	1: 24,000–1: 62,500	1: 26,000–1: 65,000
D. Meso-reconnaissance	1: 62,500–1: 250,000	1: 65,000–1: 130,000
E. Macro-reconn.	1:250,000–1: 500,000	1:130,000–1: 650,000
F. Exploratory	1:500,000–1:2,500,000	1:650,000–1:2,500,000
F_1 Generalized	<1:1,000,000	<1:1,000,000
F_2 Schematic	<1:1,000,000	<1:1,000,000

Map index of maximum reduction and minimum scale of reduction

The objective here is to select a parameter based on the map attributes discussed in the earlier part of this paper. The intention is to produce mutually exclusive classes based on characteristics which reflect the soil survey itself. The number and distribution of delineations indicate this best; therefore related attributes are employed.

The map index of maximum reduction is a useful parameter to classify maps for two reasons.

1. As defined, the map index of maximum reduction indicates the reduction necessary to bring the average-size delineation to the minimum-size delineation. This is a function of the texture of the map and indicates not only the effort made to produce the map but also the complexity of the landscape or the soil pattern.
2. The map at the minimum scale of reduction serves as a basis for comparison. It was pointed out earlier that the methodology of the survey is not indicated in the actual map scale and in only some cases when the virtual scale is used. The methodology is taken into consideration when the minimum scale of reduction is used.

The map index of maximum reduction (IMR) is grouped into five classes, and as it is related to map texture, map texture terms are employed to name these classes. The following table gives the class names and limits.

Class	Map index of maximum reduction
a. Very fine textured	$1 \leqslant \text{IMR} < 2$
b. Fine textured	$2 \leqslant \text{IMR} < 4$
c. Medium textured	$4 \leqslant \text{IMR} < 6$
d. Coarse textured	$6 \leqslant \text{IMR} < 10$
e. Very coarse textured	$10 > \text{IMR}$

Portions of a map may have finer textures than others for various reasons including landscape features, accessibility, and objectives of the survey. This texture variation in fact is an important characteristic of a map and should be indicated in any classification of maps.

From a practical point of view, it is not normally necessary to recognize more than three areas of different intensities. Depending on the number of intensities present, maps may be termed as mono-, bi- or tri-intensity maps.

Classification system

In this classification system, the three characteristics — map scale, map index of maximum reduction, and map intensity—are used. The following examples illustrate the scheme.

Case I. Mono-intensity maps. These are classified simply by combining the class for map scale and that for map index of maximum reduction.

Map code	Map name
aA	Very fine textured, ultradetailed map
cD	Medium textured, meso-reconnaissance map
dF_1	Coarse textured, generalized map

Case II. Multi-intensity maps. In such maps there are two or more areas with different map textures. The map index of maximum reduction only considers the finest textured area. However, it is useful to indicate that areas with other textures are present.

In the following nomenclature, the finest texture (on which the map index of maximum reduction is based) is indicated last. The percentage of the area occupied by the most frequent textural class, if different, is also indicated in brackets.

Map code	Map name
$a_{60}B$	Very fine (60%) textured, mesodetailed map
$e_{60}aC$	Very coarse (60%), very fine textured, macrodetailed map

$a_{60}B$ indicates that the most frequent is also the finest textured.

$e_{60}aC$ indicates that the most frequent is very coarse and the finest textured is very fine.

LITERATURE CITED

Boulaine, J. 1966. Sur la precision des cartes pédologiques. Cahiers O.R.S.T.O.M. ser. Pédologique 4:3–7.

Burrough, P. A., P. H. T. Beckett, and M. G. Jarvis. 1971. The relation between cost and utility in soil survey (I-V). J. Soil Sci. 22:359–394 and 466–489.

Hord, R. M., and W. Brooner. 1976. Land-use map accuracy criteria. Photogramm. Eng. and Remote Sensing 42(5):671–677.

Smyth, A. J. 1970. The preparation of soil survey reports. Soils Bull. No. 9. FAO, Rome.

Steur, G. G. L. 1961. Methods of soil surveying in use at the Netherlands Soil Survey Institute. Boor Spade 11:59–77.

United States Department of Agriculture, Soil Conservation Service. 1975. National soil survey technical work-planning conference (Orlando, Florida, January 26–31, 1975). Report of Committee No. 7—Kinds of soil survey. (Mimeo.)

United States of Agriculture, Soil Conservation Service. 1977. Soil survey manual, rev. ed. (4th draft, 1974–75.)

Vink, A. P. A. 1963. Planning of soil surveys in land development. Veenman and Zonen, Wageningen, Netherlands.

PART TWO

ADEQUACY OF SOIL RESOURCE INVENTORIES

Section III

Ground Truth Checking and Map Unit Composition

General Considerations on Ground Truth Checking or Quality Control

J. Schelling

QUALITY

Quality or utility of a soil inventory is the extent to which it gives a satisfactory answer to the user's questions. In this paper quality is mainly limited to precision and accuracy. When the use is not clearly specified, or if only very general questions need to be answered, precision and accuracy need not satisfy very high standards. If the user has very specific questions, such as "What is the moisture supply in the growing season in mm?" the desired quality can be exactly specified. Clearly, the quality of the inventory depends on how well it can answer the user's requests at given levels of specificity or generality.

General quality means utility of the inventory to satisfy a large number of unspecified purposes. If all purposes could be specified beforehand, criteria could be chosen to evaluate the utility for each purpose separately. The single-purpose suitabilities could be combined into a general quality index, but if the qualities were strongly variable, such an overall index would have little meaning. General quality is not recommended as a quality criterion.

Specific quality can be expressed as the utility or degree of success of the inventory's application for specific purposes or uses. An example is the utility for the prediction of the level and variation of individual crop yields.

PURPOSES OF QUALITY CONTROL

When we are convinced that quality is important, a process of quality control is needed. Webster's dictionary defines quality control as: "an aggregate of functions designed to ensure adequate quality in manufactured products by initial critical study of engineering designs, materials, processes, equipment and workmanship, followed by periodic inspection and analysis of the results of inspection to determine causes for defects, and by removal of such causes."

Quality control involves two different parties, the authority that commissioned the survey, and the surveying agency. The first will be mainly interested in the quality of

the end product. The latter will be interested in the possibilities of quality improvement, and in measures to ensure the overall quality by controlling the quality of separate parts of the survey procedure.

Quality of the end product of the survey

As the end product we can consider the soil map or some interpretation of the map as to its suitability for a purpose, e.g. a crop yield estimate. The quality assessment is only executed when the inventory is finished. The results of the quality estimation can be used in order to decide if the inventory is acceptable. The user will gain no insight into the causes of the specific quality that occurs.

Quality of separate stages of the survey procedure

The purpose of quality control can be to ascertain the quality of every stage of the survey procedure separately to indicate the causes of the quality of the end product. On the basis of this insight improved methods can be devised.

Another purpose can be to rectify the results that are below standard, such as estimates of clay content that are too low compared to laboratory analysis. These data can be rectified for every surveyor separately, providing he is consistently high or low, on the basis of sufficient data to establish the relation between his estimates and the results of the laboratory analysis. The first quality control method could be indicated as analytic, because it analyzes the quality of the separate steps of the survey procedure. The second method can be indicated as corrective quality control because it is aimed at the correction of flaws in the quality.

QUALITY CRITERIA

General quality

Quality of mapping units is usually defined in terms of purity. *Purity* is measured as the percentage of the area of all delineations of a mapping unit, in which all differentiating characteristics of the defined component are within the defined limits. The purity indicated in the survey report is 85% (USA) or 70% (Neth.). The true purity, as measured on the basis of a sample, can differ considerably from these figures. When map unit purities are averaged over all occurring map units, the mean can be indicated as "map purity."

Purity is a quality criterion of very limited value. The following drawbacks can be mentioned:

a. No distinction can be made between the case where only one or where many characteristics are outside the required limits.
b. The degree of difference between the actual and the required value of a defining characteristic has no influence.
c. The relevance and importance of the characteristics is not taken into account.
d. The width or narrowness of classes is not taken into account.

Success-percentage is another general quality criterion. It can be defined as the number of characteristics, expressed as a percentage of the total number, that are estimated correctly in the population. It can be expressed in a probabilistic way. In the case of success-percentage only the first drawback mentioned for purity does not apply. Both criteria are very general, and use of the inventory is not considered.

Specific quality

It is possible to use an adapted form of purity or success-percentage when quality estimation is for a specific purpose. In this case we consider only those characteristics that are relevant for the specific purpose. The only drawback that is eliminated in that case is the matter of relevance. All other drawbacks still apply.

Variance partitioning. The within-unit variance compared to the total variance over the map of relevant properties is a specific criterion of quality. For several relevant properties it can be averaged as a combined quality index. In the next section we will consider how this criterion could be used.

THE OBJECTS OF QUALITY CONTROL, AND SOME OF THE ASSOCIATED PROBLEMS

General

In Figure 1, the inventory is split up into two main parts: the soil survey, producing soil data; and the interpretation, producing interpretive data. General quality control will usually be applied to the output of the first part, the soil map or similar forms of soil data. Specific quality control can be applied to separate stages of the soil survey, to separate stages of the interpretation, or to interpretive data. If only a limited amount of control can be exercised it is preferable to do it on the interpretive data, since this is the most important part for the user.

Specific quality control of stages of the soil survey procedure

In Figure 2, corresponding to the left hand side of Figure 1, a schematic view is given of the steps in the soil survey procedure. Since this procedure can be different for each separate survey method, we will give only a few examples of some of these steps to illustrate the possibilities or difficulties of quality control.

The first step in almost every method will be the distinction of layers or horizons for each observation point (auger hole or pit). Different surveyors may divide into layers or horizons in diverse ways. This is a very difficult subject for quality control. Another example is the estimation of the values of soil characteristics for each horizon, e.g. clay content. For a set of soil samples, have surveyors estimate the values of the soil parameters independent of each other, and we could analyze the samples in the laboratory. The results could be compared, and it might be possible to calculate correction factors for each surveyor, thus improving the original estimates.

We will now consider the last step in the procedure, the complete soil map. On the basis of a sample we can calculate the quality for the criterion of our choice (purity, success %, or variance). See Section 3.8 of the "Guidelines for Soil Resource Inventory Characterization."

Interpretation

The interpretation (the right hand side of Figure 1, elaborated in Figure 3) can be considered as a string of models, linked by a set of products, in which the output of each model is the input of the next model. The steps are similar to those of FAO (1976) and Beek (1978).

The quality of the end product (either soil qualities, suitability or yield, or economic value) can be established. If we analyze the different steps in this string it is apparent that both the quality of the inputs and the quality of the models influence the quality of

Fig 1

248

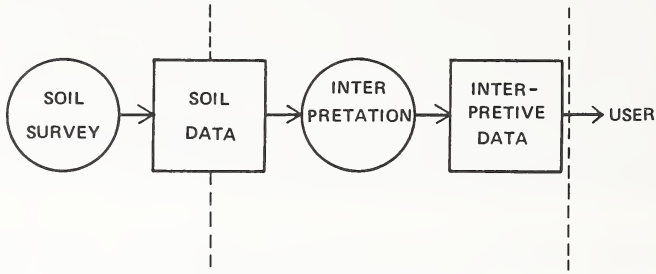


Fig. 2

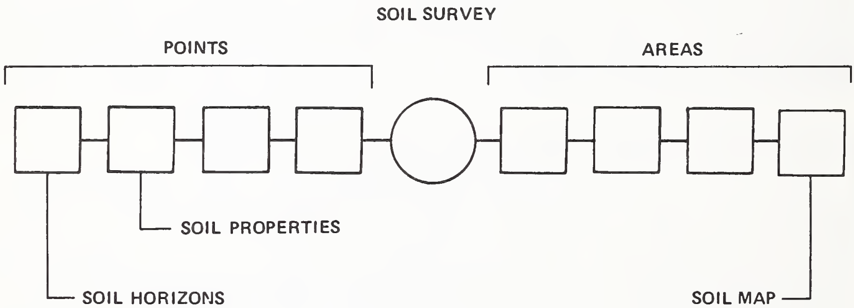
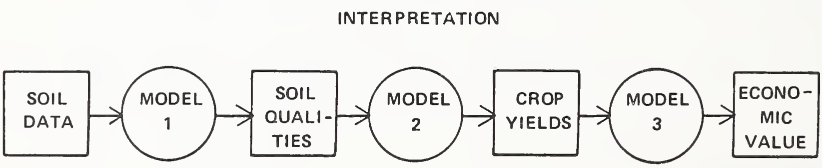


Fig. 3



the products. The models can be fairly primitive, such as a "lookup" table, for instance, with each soil unit and the level of each soil quality. A more precise model is a mathematical function (e.g. a × % clay + b × % organic matter + c = mm available moisture). A very sophisticated kind of model is, for instance, a computer simulation model for water supply to a crop, from the ground-water and unsaturated flow, based on dynamic variables.

It is essential to verify the models for the range of relevant variables that occur in the survey area. In order to limit the amount of work needed for quality control, a sensitivity analysis of the model is important. This analysis is a test to find out the effect of different levels of the separate inputs on the output. Only those inputs that have a considerable influence on the output of the model are relevant for quality control.

SAMPLING SCHEMES

The selection of an adequate sampling scheme (including sample size) is a matter of statistical requirements, costs and manpower, accessibility of the terrain, and the requirements of the user. Statistical requirements are the random aspect of the sample; it should be representative for the population of objects under consideration. Usually for purposes of map quality some form of stratification is chosen. No general rules can be given for this choice.

Since costs and manpower will impose severe restrictions on the quality control, the necessary work should be kept to a minimum. The accessibility of the terrain may be so difficult that the surveyor is severely restricted in his movements. In that case, traverses or transects can be used for quality control. Such a sampling scheme requires a specific estimation procedure. The requirements of the user will indicate the aspects of quality control and the required accuracy. When all relevant details have been considered, a suitable sampling procedure can be chosen.

USING THE RESULTS OF QUALITY CONTROL

How the user benefits from quality control

For the user the outcome of the quality control indicates the limitations in the application of the inventory. When we have more experience with quality control, it may be possible to set quality standards when commissioning surveys and to accept or reject on the basis of a quality check by an independent authority.

How the survey organization can benefit from quality control

Analytic quality control applied to surveys executed by different methods can highlight methodological weaknesses. Corrective quality control enables observations to be adjusted during the course of the survey, and thus improves the quality.

It is evident that any correction of values of soil properties should also lead to correction of subsequent steps in the survey and interpretation procedure. This implies that it makes little sense to execute any of these later steps before corrections have been completed. This is evident, for instance, when the purity criterion is used and if on the basis of the sampling, purity values have to be corrected considerably.

For the individual surveyor and the survey organization quality control can lead to a considerable increase in knowledge about survey methods, and thus to their improvement in the future. Since survey methods are among the most neglected subjects of research, this can prove to be a very rewarding subject of investigation.

LITERATURE CITED

ARNOLD, R. W., A. VAN WAMBEKE, H. ESWARAN, and T. R. FORBES. 1978. Guidelines for soil resource inventory characterization (draft). Dept. of Agronomy, Cornell Univ., Ithaca, NY.

BEEK, K. J. 1978. Land evaluation for agricultural development. International Institute for Land Reclamation and Development (ILRI) Publication No. 23. Wageningen, The Netherlands.

FOOD AND AGRICULTURE ORGANIZATION (FAO). 1976. A framework for land evaluation. Soils Bull. No. 32. FAO, Rome.

Some Concepts of Ground Truth Checking as a Tool in Quality Control of Soil Resource Inventories

R. W. Arnold

CORRELATION AS A CONTROL MECHANISM

In any ongoing soil resource inventory, the procedure of soil correlation embodies most of the elements of quality control. A review of existing support information — other maps, reports, and background data—aids in reducing efforts that might otherwise duplicate such work. Developing a meaningful plan of work that spells out the objectives of the inventory and provides a framework for its conduct gives direction and purpose to the endeavor. The preliminary legend can be examined and checked, and potential problems anticipated. As work progresses the backstop information and initial interpretations can be tested with users and for internal reliability. Field maps and techniques, base maps for publication and formats for the final products are all scrutinized throughout the inventory.

As Dr. Schelling clearly pointed out, there are many points or stages that receive attention, or can receive attention. In some places insufficient time and effort is given to soil correlation and eventually quality is adversely affected. A single project may have everything done right—it is a success—and yet the results may apply only to that limited project. It may take years to go back and obtain the extra information that would have helped someone else in another place or at a different time.

PUBLISHED SURVEYS REFLECT MODELS

When we deal with existing published soil resource inventories the rules of the game are changed. You can't take corrective measures to improve the inventory because the work has already been done. The lack of information on how quality was controlled made a checklist a must. Competent soil scientists can then "second guess" what might have happened and consequently they can make judgments about the adequacy of an existing inventory for new or additional interpretations.

Fortunately soil survey is a discipline based on models, and all pedologists build models, test models, and revise models as their main daily task. The approach is a

learned skill, and there are truly craftsmen among the cadre of pedologists struggling with a continuum that is to be parceled into seemingly discrete separate units in the landscape. Soil maps, like all other maps, are abstractions of reality. They represent the models of soil geographers whose base skills are derived from knowledge of stratigraphy, geomorphology, pattern recognition, probability, and correlations, and whose expertise is determined by powers of observation and empirical relationships and a desire to be as right as possible, for the circumstances.

Mankind has made relatively few soils, thank goodness, because man appears to be far less predictable than nature. On the other hand, man seldom accepts land as he finds it and has modified the developmental and distributional processes on the earth's surface to varying degrees and for varying periods of time. Models are developed to explain and predict, thus man himself defined soils and their occurrence as simplified models of an extremely complex ecologically balanced system and suddenly was faced with variability. Some he could predict or account for, but much of it still escapes his imperfect models.

What happens when we ground truth an existing soil resource inventory? Conceptually we reconstruct the models that were used: the model of soil itself, the model of classification, the model of landscape-soil relationships, even the model of probability and reliability. How much easier it would be if these models had been stated and had been a part of the documents of the inventory. But never mind, a challenge to the intellect is almost always rewarding. And as Dr. Schelling noted—a sensitivity analysis may be in order.

CONCEPT OF BASE MAP ACCURACY

Does the choice of a base map influence the utility of a soil resource inventory? Surely it does at some level of use, or at some scale. *How much* of something is better placed in a graph or a table, but *where* is best placed on a map. The relation of the map and the ground location can make or break some decisions. Fragiochrepts dominate a portion of the Northeastern United States and accurate location relative to Hapludolls in the Midwestern states is generally not required. But if you have a small parcel for a house and the soils are dominantly Fragiochrepts it is darned important to know where they are because of the severe limitations they impose on construction.

Base maps need enough ground control reference points for the decisions requiring location considerations. As so strikingly illustrated in the Sri Lanka slides, a map as a model of location of a single-bullock padi is ridiculous. The man on the land has more knowledge of reality of location than any abstraction can hope to impart.

Map accuracy standards are used in most parts of the world. How do published soil maps stand up to such standards? How do you check this for maps where the representation of location will have an influence? The details are shown in the posters so let me briefly explain how we approached the question. Accurate location of well-defined points determine the level of acceptance, yet it is a sampling and therefore subject to error and probability. Generally if 90% of well-defined points on the ground are placed within small tolerance areas on the map it meets an acceptable level of accuracy. But what is the accuracy of the map for location? Assume 10 points out of 10 points are within the tolerance area. The lower confidence limit, with only a 1 in 20

chance of being wrong, is about 72% and the upper limit is 100%—thus the map is at least 72% accurate for ground control reference points. If 9 out of 10 were O.K., the at least statement lowers to about 60% and the upper limit is about 96%.

If you want to be at least 85% accurate (this is lower confidence limit) 19 times out of 20 then you'll need about 18 points, all of them within tolerance.

RELEVANCE OF LOCATIONAL ACCURACY

Want to field check a point, or a location, by yourself? Sight a compass bearing and using your calibrated step go find it. We have calculated how far you can go and how wide the acceptable width (or tolerance area) will be when you get there for a number of map scales, and for deviations you might make following the compass. We don't recommend such checking but it gives you a sense of what some users are up against. More importantly you can estimate how far apart reference points can be for any scale of map and still give an acceptably accurate map for locational purposes. In turn the number of recognizable reference points can be used to estimate levels of usefulness of the base map for locational purposes. And this we do recommend. One quickly appreciates the value of air photo backgrounds for resource maps—they usually have sufficient points to permit reliable judgments of relative location.

An interesting aspect of locational accuracy is the impact on errors associated with small delineations on maps. Minimum-size and least-size delineations often indicate the amount of detail that may exist in the field and suggest the level of intensity of observations necessary to show the areas. Generally they are areas of marked contrast that affect the use or management of the land. Slight displacements or exaggerations of these small areas generate enormous errors of size and composition when related to ground truth. Don't be dismayed—unless you are adding up hundredths or tenths of hectares and expect those numbers to have great significance. The model used to map soil bodies of highly contrasting and often limiting sets of properties is one that emphasizes the importance of calling attention to such conditions. The line on the map may represent 15 meters and a gully is only 5 meters wide but the fact it is 10 meters deep and disrupts all normal mechanized activities seems important enough to call to someone's attention. The map can be as good as the model and if the model is relevant for the purpose—use it.

SPATIAL VARIABILITY

Let us briefly consider the sensitive side of a pedologist. Although he didn't create nature nor the laws of distribution, he is sensitive about his portrayal of reality and tends to be apologetic for the large amount of variability that exists. People in laboratories and greenhouses control their experiments, replicate their trials, minimize spurious results by mass action and smugly point a finger of shame at the large amount of inclusions measured in delineations of soil map units. The experiments of pedologists are a lot more fun, however. They test their models with every line drawn or imagined. They find mismatches of concept and reality and it leads to improved models. And suddenly the vision comes! A slow aching realization that variability is the fundamental property of nature, and all we need do is report our findings objectively and honestly and check the sensitivity of these results relative to the predicted

outcomes. Who cares how many samples are needed to reach 90% accuracy—or the number of transects to estimate the composition of a unit to within plus or minus 10% of the population's mean? These are indirect ways of indicating variability.

The composition of map delineations can be presented as statements of confidence limits — the at least statement and the at most statement based on the available information obtained from some random sampling scheme. Graphical solutions relieve the ground truth checker of the burden of formalized, messy calculations, restores his morale and places him once again in the position of intellectually unravelling man's models of nature. Some models are better than others, whereas some can't be improved because reality and map scales are terribly mismatched.

THE CHALLENGE OF INTERPRETATION

Most of you will assume that I've been referring to taxonomic composition of soil map units. Because soil maps are named with a taxonomy it is an important test of adequacy of the naming and description of those delineated area. However, in an appraisal of adequacy of a soil resource inventory for a specific purpose, or many specific purposes as the case may be, it was pointed out that soil properties and qualities relevant and crucial or critical for that purpose need to be evaluated.

The list of relevant features must first be decided upon before the ground-truth checking begins. Then each field observation can include as many of those parameters as is possible. The testing of taxonomic models, vegetation models, landscape models, property models, suitability models, limitation models and others can be done. Each interpretation, each set of included features, and each predictive model associated with the existing delineations in an inventory can be stated in terms of confidence limits at given probability levels.

Who sets the acceptable level of accuracy, of reliability, of adequacy? The users do, of course! Educating them in the ways of the probabilities of nature likely is our biggest challenge ahead.

Evaluation of Map Unit Composition by the Random Transect Method

B. F. Hajek and C. A. Steers

Accurate composition of individual soil delineations can be obtained from closely placed transect data (Bartelli and DeMent, 1968; McCormack and Wilding, 1969; Powell and Springer, 1965; Johnson, W. M. 1961. Transect method for determination of the composition of soil mapping units. Soil Survey Technical Notes. U.S.D.A., S.C.S.; Mokma, D. L., and E. P. Whiteside. Point-transect method for determining mapping unit composition or legend accuracy. 1974. Annual Report. MC-109 Project, Michigan State Univ., East Lansing, MI.) However, in dissected heavily wooded areas a soil scientist often can spend more time gathering transect data than he spends mapping the soil by conventional means. In these areas soil scientists also have problems in adequately defining inclusions and determining what is typical for a mapping unit. The major difficulty is statistical problems such as the number of samples required, bias, systemic sampling procedures, and the definition of computable soil populations (White, 1966; Protz, et al., 1968).

A procedure for random sampling of mapping units and a statistical method for analyzing field data has been evaluated in five Alabama soil surveys. Taxonomic composition, consistency of delineations, and minimum number of transects needed for mapping unit characterization were determined by routine field examination, random transect investigation, and statistical analysis of field data.

METHODS

This random transect method is designed primarily for use in wooded areas, areas of complex terrain of limited accessibility, or other areas where need of average-size delineations is in excess of 120 ha. In the past many of these mapping units would have been called complexes, associations, undifferentiated units, or land types (Soil Survey Staff, 1951).

The design was made with the idea of use in mapping order 2 and 3 soil surveys, previously designated as reconnaissance surveys. However, as a means of quality control, its use could be expanded to the sampling of soil populations at any intensity of soil survey.

The soil individuals that make up a population are difficult to define (Knox, 1965). As an aid in defining the soil population to be sampled, the following "target" population terms were used (Griffiths, 1967, p. 14–15): hypothetical, existent, available, and random. To utilize most of the desirable bias that the soil scientist has acquired from his field studies and soil observations and to minimize sampling bias, the population terminology has been altered to connote soil populations as follows:

Hypothetical population: that portion of the earth's surface which at one time existed or could have existed in soil pedons. It is not represented in any set of samples because of bias, erosion, or misinterpretation of soil-forming processes.

Existent population: that portion of the earth's surface which presently exists in soil pedons. This population is real but cannot be sampled in its entirety because of inaccessibility and time limitations. This is the true or target population for soil investigation but it cannot be sampled as all individuals of the soil population may be present but are not equally likely to be encountered in a sampling program.

Available population: that population which is readily accessible for point investigation along a line traverse. This population should be investigated and properly sampled. It should be investigated to the extent that the sampler knows that the sample area represents the existent population.

Random population: that population actually sampled. It should represent and typify the available population.

The random transect method for soil survey was developed by use of the entire available population of transects obtained during the course of a soil survey in Talladega County, Alabama (Cotton et al., 1974; Steers and Hajek. 1974. Agronomy Abstracts. Am. Soc. of Agron., Madison, WI). In addition, randomly selected transects from reconnaissance mapping units in Geneva, Mobile, Clarke, and Cleburne Counties (Alabama) were used.

The method used involved the following steps:

1. Soils were mapped and investigated in the field by conventional means. An adequate amount of time was devoted to soil series identification and landscape evaluation so that key soil association patterns for mapping units were established. After mapping units were designed, areas were traversed and delineated on field sheets. All delineations were investigated to some extent and projections were checked by on-site soil investigation.
2. As a part of field mapping and investigation, available transects were located which in the soil scientist's judgment represented specific delineations and typified existent populations. These available transects were distributed evenly throughout the mapping unit delineations as they existed in the survey areas and characterized areas equal to the expected average management size plots. Alabama has used a ratio of 1 transect for every 120 to 240 ha in reconnaissance surveys for woodland planning. This ratio will vary with area and needs. Each delineation, no matter how large or small, included a minimum of 1 available transect. Transects were commonly located at right angles to drainage patterns, included as much of the complete range in elevation as possible, and represented the typical landscape for the area delineated.
3. A record of each available transect was maintained. After a sufficient area of a particular mapping unit was mapped (about 20% of its expected occurrence) transects were selected by use of a random numbers table. Total number of transects for initial sampling varied with extent of the unit, number of delineations, and complexity of soil patterns.

4. Random transects were sampled by the point intercept method. Transects included between 10 and 20 observations. Intervals between observations varied from 30 to 90 m depending on length of transects. Data were recorded in terms of percent composition of various included soils.
5. Statistical analysis included a simple one-way analysis of variance (Steel and Torrie, 1960) that provided estimates of variance and gave the following useful parameters:
   a. arithmetic mean for each specific soil component,
   b. number of traverses (n) needed to determine soil components at a specific confidence (80%), and
   c. confidence interval (of a mean) at a specific level of confidence (80%).
6. The statistical data were used by party leaders in writing their mapping unit descriptions. This data became the basis for land use planning and interpretations before completion of the survey. A few mapping units were inconsistent in soil composition at the first sampling. Further study of these mapping units revealed that some delineations were mapped too broadly for the original mapping unit standards. In these few instances, a reinvestigation of questionable delineations was performed and an additional mapping unit was designed and evaluated by the same random transect procedures. Such inconsistencies showed up at the time transects were completed and before statistical analysis.
7. After 80–100 percent of field mapping is completed another random sampling is made. A guide for the number of transects (sample size) needed is determined by considering data from the initial sample. In determining the number of transects for final sampling, we used "n" values that gave the transects needed to characterize about 80 percent of soil occurrence. Populations for final random sampling include the complete available transect population and each has an equal possibility of being selected. These data are analyzed in the same manner as the initial sample, summarized, recorded, and used in preparation of the soil survey manuscripts.

This procedure has shown that many mapping units in a survey area can be characterized with less than 10 transects at 80% confidence. In some cases it may be necessary to group soil series into similar interpretive units to reduce transect numbers and to present data that can be used.

Examples 1–4 show the field data form used, summarized data, a statistical worksheet, and an example of a calculator printout for the Esto series in the Eustis-Troup association in Mobile County, Alabama. The number of transects needed to characterize this unit would be based on the largest "n" value calculated from the series that make up 80 percent of the mapping unit, that is, Eustis, Esto, Troup, and Norfolk.

Example 5 shows data for two associations each in five Alabama counties. These data are from the initial sampling after about 20 percent of the expected occurrence had been mapped. Recently, after 95 percent of mapping was completed, a final sampling using the calculated n-value confirmed these results.

LITERATURE CITED

Bartelli, L. J., and J. A. DeMent. 1968, Soil survey—guide for forest management decisions in Southern Appalachians. p. 427–434. *In* Proc., Third North American Forest Soils Conference. North Carolina State University, Raleigh, NC.

Cotton, J. A., L. A. Dungan, G. L. Hickman, and C. F. Montgomery. 1974. Soil survey of Talladega County, Alabama. U.S.D.A., Soil Conservation Service, Washington, DC.

Griffiths, J. C. 1967. Scientific methods in analysis of sediments. McGraw-Hill Book Co., New York.

Knox, E. G. 1965. Soil individuals and soil classification. Soil Sci. Soc. Am. Proc. 29:79–84.

McCormack, D. E., and L. P. Wilding. 1969. Variation of soil properties within mapping units of soils with contrasting substrata in Northwestern Ohio. Soil Sci. Soc. Am. Proc. 33:587–593.

Powell, J. C., and M. R. Springer. 1965. Composition and precision of classification of several mapping units of the Appling, Cecil and Lloyd Series in Walton County, Georgia. Soil Sci. Soc. Am. Proc. 29:454–458.

Protz, R., E. W. Presant, and R. W. Arnold. 1968. Establishment of the model profile and measurement of variability within a soil land form unit. Can. J. Soil Sci. 48:7–19.

Soil Survey Staff. 1951. Soil survey manual. U.S. Dept. Agric. Handbk. No. 18. U.S. Govt. Printing Office, Washington, DC 20402.

Steel, R. G. B., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., New York.

White, E. M. 1966. Validity of the transect method for estimating compositions of soil-map areas. Soil Sci. Soc. Am. Proc. 30:129–130.

EXAMPLE 1

AL-95 (8-67)
AUBURN, ALABAMA

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL TRANSECT DATA SHEET

Page No. ________

County | Soil Mapping Unit

Transect No. | Direction | Boring Interval | Length

Starting Location

Date | Photo | By

Remarks

Profile No. ________

Percent Slope | Aspect | Erosion

Position on Slope

Horizon	Depth	Color	Tex-ture	Struc-ture	Consis-tence	Mottles	Frag-ments	Clay Films	pH

Additional Notes

Series

Classification

Profile No. ________

Percent Slope | Aspect | Erosion

Position on Slope

Horizon	Depth	Color	Tex-ture	Struc ture	Consis-tence	Mottles	Frag-ments	Clay Films	pH

Additional Notes

Series

Classification

Profile No. ________

Percent Slope | Aspect | Erosion

Position on Slope

Horizon	Depth	Color	Tex-ture	Struc-ture	Consis-tence	Mottles	Frag-ments	Clay Films	pH

Additional Notes

Series

Classification

EXAMPLE 2

ASSOCIATION

Eustis—Troup
(Association; Hilly)

Soil Series	Transect Numbers														
	26	32	33	34	36	37	38	42	43	44	46	47	48	49	50
	%														
Eustis	37	25	29	37		13	13	8			8	25	9	36	
Dorovan	9	8			7		6				21	16			
Esto	18	17	14	10	28	13	13	15	45	18	35		17		17
Osier	9	8	7	9	7	8	6	8				25	8	19	
Troup	18	25	36		43	33	31		19	8	14	17		36	34
Bibb	9		7	9				8	9	8	8		17		8
Norfolk		17	7	18	15	33	31	61	27	58	14	17	41	9	41
Goldsboro				18						8			8		

Mobile County, AL. by M.G.M. and E.H.M.

ASSOCIATION ***Eustis-Troup*** ***EXAMPLE 3***

STATISTICAL ANALYSIS

	Soils							
	Eustis	**Dorovan**	**Esto**	**Osier**	**Troup**	**Bibb**	**Norfolk**	**Goldsboro**
ΣX	240	67	260	114	314	83	389	34
$\overline{X} = \frac{\Sigma X}{n}$	16	4.5	17.3	7.6	20.9	5.5	25.9	2.2
$\Sigma(X^2)$	6672	927	6408	1538	9506	837	14679	452
$(\Sigma X)^2$	57600	4489	67600	12996	98596	7744	151321	1156
$\Sigma(X-\overline{X})^2 = \Sigma(X^2) - \frac{(\Sigma X)^2}{n}$	2832.06	627.20	1901.20	672.00	2933.00	378.00	4590.60	3752.0
$S^2 = \frac{\Sigma(X-\overline{X})^2}{n-1}$	202.29	44.8	135.8	48.0	209.5	27.0	327.9	26.8
$S_{\overline{X}}^2 = \frac{s^2}{n}$	13.47	2.99	9.05	3.20	13.97	1.80	21.86	1.79
$S_{\overline{X}}$	3.67	1.73	3.00	1.79	3.74	1.34	4.68	1.34
confidence interval (±%)	4.94	2.33	4.04	2.41	5.03	1.80	6.29	1.80
sample size $n = \frac{t_1^2 s^2}{d^2}$	16	41	9	16	10	17	10	103

$t_{0.8}$; $d = \overline{X}$ (0.3)

EXAMPLE 4

Monroe Calculator Print-Out
Esto

		%	
		18.000	Σ ′
		17.000	Σ ′
		14.000	Σ ′
		10.000	Σ ′
		28.000	Σ ′
		13.000	Σ ′
		13.000	Σ ′
		15.000	Σ ′
		45.000	Σ ′
		18.000	Σ ′
		35.000	Σ ′
		0.000	Σ ′
		17.000	Σ ′
		0.000	Σ ′
		17.000	Σ ′
	$\bar{x}$	17.333	
	n	9.086	A
		13.286	A
confidence interval at 80%		21.380	A

EXAMPLE 5

Alabama County	Association Name	Major Soil Series & Groups	Arithmetic Mean	Confidence Interval	Transects Needed
			%	±%	
Clark	Lucedale assoc., nearly level	Lucedale	88	2	2
	Cravens-Sawyer-Angie assoc., nearly level	Cravens	27	6	2
		2w8	73	7	2
Cleburne	Madison assoc., hilly	Madison	78	7	2
	Madison-Louisa assoc. steep	Madison	43	9	2
Geneva	Chastain and Bibb soils	Chastain	45	23	9
		2w9	70	14	2
	Bigbee-Kalmia-Eunola assoc.	Kalmia	27	9	7
Mobile	Smithton assoc., undulating	Smithton	44	8	3
		wet soils	72	4	2
		2w9-Smithton	58	6	2
	Troup assoc. hilly	Troup	21	5	9
		3s2-Troup	37	7	6
Talladega	Tallapoosa-Tatum complex, 6 to 15% slope	Tallapoosa	43	7	2
	Tallapoosa-Tatum assoc., hilly	Tallapoosa	54	5	2

PART THREE

PRESENTATION OF SOIL RESOURCE INVENTORY INFORMATION TO PLANNERS

Maximizing Participative Planning: Cultural and Psychological Aspects of User-Centered Soil Resource Inventory Data Preparation and Presentation

Gordon C. Thomasson

In recent years increasing attention has been given to participation as an essential variable in the overall process of planning for development. While many schemes have been attempted that have not included participation from the onset of the planning process, the number of such ventures that can, in retrospect, be termed a success is in fact small. Some projects have paid lip service to the concept of participation, including local identification of problems, setting of priorities, and developing responses. Nevertheless, internal studies by the World Bank (Saunders, 1977), and USAID (Tendler, 1976), concluded that in the overwhelming majority of projects, input from existing indigenous organizations was virtually nonexistent at the project design and planning stage.

While participation is not the panacea that will cure all the ills that can beset development projects, it does promise help in solving some of the problems that have been encountered. What follows is an intentionally incomplete outline of cultural and psychological variables that should be taken into account in order to facilitate more widespread and informed participation in the planning process on the project or scheme level by making Soil Resource Inventory (SRI) information more accessible and intelligible to its ultimate users.

I will present some general guides for effective information transfer that soil scientists, cartographers and planners might do well to consider. I am suggesting that in each project an effort must be made to tailor SRI information to the users' cultural understanding and technological adaptation to the ecology of their area, rather than expecting the users to adapt to some universal system of SRI information presentation. In order to maximize participation it probably will be necessary to call on social scientists such as anthropologists and psychologists to serve as an interface between sources of SRI information (soil scientists and cartographers) on the one hand and planners, those

involved with implementation and participants, on the other. This task might be described as translation, if we use that word in a broad cultural rather than a narrow linguistic sense.

SCALE AND POTENTIAL USERS

It is important, at this point, to recognize that SRI information can be gathered and presented at different scales in numerous formats according to the type and scale of land use planning that is intended. To be effective, SRI information transfer, as is the case with any other effort at intercultural or interdisciplinary communication, must proceed on the basis of who the (probable) intended users of the information will be. There is a fairly consistent relationship between map scale and level of use: the smaller the scale the more likely the project will involve national or international levels of planning. Whatever the scale of map or report being made or level of planning being done, those involved with SRI information transfer should be sensitive to such diverse variables as physiological differences, cultural backgrounds, and average educational levels of users, as well as the probable intended uses of the SRI information.

SMALL AND INTERMEDIATE SCALE MAPS, REPORTS AND PLANNING

Small-scale maps (<1:650,000), and reports generated from them, are generally prepared for and used by planners who are working on projects of national or international scope. Intermediate-scale maps, with scales of from 1:13,000 to 1:650,000, and reports deriving from them, are often used in smaller nations and within regions for general planning. A majority of the users of small- and intermediate-scale based information will be university-educated and members of what might be termed a global-technocratic culture. Their level of education and/or access to specialists who can interpret reports will enable them to sort through the peculiarities of typically presented SRI information with only a small amount of effort. With the exception of politicians involved in planning at these levels, there is a significant probability that the personal, ethnic, and/or cultural background of planners may not correspond to that of the people ultimately involved in a specific development project. Differences in the educations received by planners at this level may create some problems in SRI information transfer. Former Dutch colonies preserve a style of education that is distinct from what were British, French, American, or German colonies, and this can result in difficulties with regard to both the form and content of SRI information presentation. For example, some countries such as the U.S. are only now converting to the metric system and thus may be less efficient in their use of international resources by virtue of their prior training. So even on the highest levels SRI information transfer should take into account local educational backgrounds if we wish to maximize the efficiency of information transfer. Larger questions regarding differences in types of education and preferred styles of information presentation remain to be researched.

Planning on intermediate levels will primarily be concerned with meeting national goals within regions, and feasibility will often be in terms of "cost-benefit" calcula-

tions that do not take into account social and long-term environmental costs. Intermediate planning, while often faced with the task of siting general areas for development, still uses SRI information as only one of a great many inputs to what is also a political process. Nevertheless, the results of such regional planning are often spread in two directions: to international agencies, for funding and technical assistance, and to colleagues and participants within the region in question, for eventual implementation. It is at this juncture that distinct styles of SRI information presentation can be most useful, if they are put in a format that is intelligible to those involved.

LARGE SCALE MAPS AND REPORTS

Large-scale maps (>1:13,000) and reports are, or should be, used when siting, planning, and implementing specific schemes. These cannot be simply enlargements of small-scale maps, but must be based on more extensive surveys or reviews of existing soil resource information. It is on this, the project level, that maximum participation is needed and is possible. Planning of individual parcels, siting of communities, development of infrastructure and related problems can only be done effectively with a maximum availability of relevant SRI information. However, the larger the scale and the more participants involved in the planning process, the less we can assume that western-style technical methods of data presentation will be effective. This is not to say that those involved are less intelligent. Rather it is to suggest that the particular type of training shared by a majority of those involved in national and regional planning cannot be taken for granted at the local level. It is here that significant improvements are possible in SRI information transfer that will facilitate more widespread participation in the planning process.

USERS OF LARGE SCALE MAPS

Technicians, extension agents, etc.

Besides those planners who are working at the project or scheme level, there will be a number of people who are more or less conversant with SRI information as it is now presented. These individuals may have a certificate or diploma, and often have had considerable experience in the field. Their cultural background, however, may not be from the current project area and they may not speak the local dialect. They will have a significant role in activities such as the siting of towns, locating parcels, and helping match crops and soils. They represent, depending on one's point of view, either the key or the major obstacle to widespread participation. If their help can be enlisted in making sure that SRI information is made useful on the local level, then a major hurdle will have been overcome. If, on the other hand, they are not encouraged to become, as it were, bilingual, then the likelihood of meaningful participation is slight. Incentives and training must be made available to such individuals to assist them in facilitating participation. Their training as well as their position makes them the logical intermediaries between sources of SRI information and the ultimately intended audience.

Local leaders

Depending on the country in question, local leaders may have had at least a high school education. Their cultural background is usually the same as that of the project partici-

pants. In most cases they will be able to speak the local dialect. They are an inevitable and usually valuable part of the process of developing infrastructure, siting of homes, and especially allocating lands to new settlers, etc. Needless to say, many opportunities for exploitation are to be found at this level. If an effort is made to make SRI information intelligible to everyone involved in the project, such exploitation will be more obvious and difficult.

Participants

Whether an existing agricultural area is to be irrigated or new areas are to be opened, if local or transmigrant populations are to be involved, or if new crops are to be introduced, the success of the project will finally depend on how those who are to work the land are integrated into the project. The level of formal education of participants will, more often than not, be low. They may or may not be literate; some will have completed an elementary education. When a project combines both urban and rural members (and no scheme should be attempted with purely urban populations), some mechanism should be established for training prior to entry into the project. The cultural and language backgrounds will hopefully be similar. Ideally, settlers will be locals, or from an ecologically similar area (Moran, 1976). The more diverse their origins and the less familiar they are with the type of agriculture being attempted, the less likely SRI information transfer will be effective, and both participation in and the success of the project will be jeopardized. The probable uses which project participants would have for SRI information include such diverse tasks as matching soils and crops, avoiding problems such as uncontrolled drainage of acid sulfate soils, siting homes with regard to both structural stability and sanitation, and generally integrating into the project as a whole.

The foregoing is intended to stress the need for and the problems inherent in involving the settler in participation. If SRI information transfer is attempted that disregards the low levels of formal schooling typical among participants, or if their culture and language are ignored, participation will be superficial and information transfer will be minimal. What follows are a few guidelines toward making SRI information intelligible and useful on the local level. It is intended as a sketchy model of how participation might, in general, be facilitated by paying attention to and taking advantage of the assets of local culture and indigenous technology, as well as making the most technical information more readily intelligible on the local level to the small farmer.

VARIABLES THAT CAN FACILITATE EFFECTIVE SRI INFORMATION TRANSFER

Physiological variables

A prime example of a physiological variable that has not been considered in the transfer of SRI information involves color vision. Even in temperate regions visual deficiencies which involve the genetically caused absence or collapse of function of one or another type of receptor cells in the eye and result in red, green, or blue partial or total "color blindness" have not been taken into account in the preparation of many color map legends. (See for instance the current New York State Soils Map.) This is in spite of the fact that 4.3% of Caucasian populations have some color vision deficiencies.

Among populations located closer to the equator, another problem in color perception exists. It is known that among peoples indigenous to the tropics, apart from regular color blindness, a high degree of optical attenuation of short wave-length radiation is common and causes a significant lowering in the ability to discriminate between shades of blue and green. This results from what are in some cases dietary, and in other cases genetically caused, accumulations of pigment within the eye. The accumulation of intraocular pigmentation in indigenous populations near the equator is recognized to be an adaptive trade-off: differential sensitivity to blue-green visual phenomena is reduced among these peoples while there is an increased protection against the potentially carcinogenic higher incidence of ultraviolet and near-ultraviolet radiation common closer to the equator, as well as generally heightened visual acuity due to the filtration that occurs (Bornstein, 1975). This reduction in sensitivity to blue-green distinctions generally has not been taken into account in making map legends for use in the tropics. In many cultures decreased optical sensitivity to blue-green distinctions is reflected in the absence of such terms in those languages. While planners and government leaders with a significant amount of formal education may have learned that other cultures distinguish colors that their own language does not, and have learned to compensate for the handicap they would otherwise experience in using international materials, many people are not even aware there is a problem. For these people, the choice of two, at best marginally differentiated, colors to indicate very distinct soil conditions in a map legend may be quite inefficient. A related, but to my knowledge unexplored question is whether this reduced blue-green sensitivity in any way biases determination of soil color using a Munsell chart. This simply reinforces my point that if effective information sharing is a goal, neither psychophysiological nor cultural variables can be ignored or taken for granted.

Cultural variables

Coupled with physiological variables there may be a number of cultural factors related to color that should be considered. In the United States Department of Agriculture's efforts to make information for land use planning more accessible, some color symbols common in the U.S. have been adopted. Around the world, many urban centers use electric traffic control signals similar to those used at major road intersections in the United States. They employ three colors: red, yellow, and green. These are almost universally understood as meaning red = stop, yellow = caution, and green = go. I say almost, because color-blind individuals are taught that the top light = stop, the middle light = caution, and the bottom light = go. With that exception, the symbolism of these colors is widely known and understood. Land use maps are often coded using these colors to symbolize the suitability of the land for the intended use. In other cultures, even though they may have automobiles and traffic signals, there are other symbolic meanings attached to various colors which may be much more useful and widely understood if linked to particular soil characteristics in a map legend.

Ignoring color symbolism can create problems ranging from simple inefficiencies to violations of taboos. Taking local color symbolism into account can significantly increase the content communicated by the map legend itself, just as red = stop does in America. It also must be recognized that in many societies soils are named and differentiated on the basis of their color. While it might be difficult to use solid black or dark red for a soil map unit designation when a people name a particular soil by one of those colors, even crosshatching with faint lines in these colors can allow cognitive

identification of such types of soil with soil names and map units by local users. Where lighter colors and color names are correlated in a culture, solid colors can be used on maps without loss of other important details. The main point is to try and correlate map legends with the local culture whenever possible. Local ethnocategories which, like "black," "yellow," and "red" soil names, also reflect significant agronomic distinctions, should not be ignored.

INDIGENOUS SOIL CLASSIFICATION SYSTEMS

Perhaps the most important way in which SRI information can be effectively transferred to participants and planners on the local level is if the data is integrated with the participants' often substantial knowledge of soils, rather than expecting them to adapt to one or another of the numerous and constantly changing scientific classification systems. It is not hard to hypothesize a locality which has had inputs successively from colonial French, American, FAO, and Russian development teams. Farmers living in such an area would have to spend a large amount of time simply learning new terminologies in order to understand the technicians. For example, if one examines the labels assigned to one "lateritic" pedon since the 1940s, the number of potential name changes is amazing to the non-soil scientist. The changes will continue (as the current committee to review the classification of Oxisols evidences) as well they should, given the constantly evolving nature of science, but to expect non-soil scientists to keep abreast of such developments would be as unreasonable as expecting soil scientists to be current on sociological jargon. It is obviously much more practical, whenever possible, to encode technical inputs within an indigenous and usually relatively stable soil classification system, so that immediately useful knowledge can be integrated within the local culture. This is important because while classifications and entire taxonomies can often change, sound soil management practices are much less likely to be completely overturned with the same frequency. Moreover, indigenous classification systems are usually quite sophisticated and well adapted to local conditions. Soil scientists may find a great deal worth learning from peoples who often are stores of millenia of practical empirical data about their own lands, even though their "science" is neither statistical nor published. Communication, ultimately, must be a two-way process.

> In Bangladesh, for example, farmers have their own traditional system of land classification . . . based on land levels in relation to flooding which govern the kinds of crops that can be grown. In this traditional system, "highland" (uchu jumi) is land lying above normal flood level which can be used for annual or perennial dryland crops (sugarcane, bananas, fruit trees). "Medium land" (madhyum jumi) is land flooded up to about six feet deep during the monsoon season. "Medium highland" (majhari uchu jumi) is land normally flooded only one to three feet deep during the monsoon season on which transplanted aman paddy rice can be grown (aus paddy rice and jute can also be grown on this land before the transplanting of the aman crop). "Medium lowland" (majhari nichu jumi) is land normally flooded up to three to six feet deep during the monsoon season, too deep for rice to be transplanted, but still suitable for broadcast rices and jute—broadcast (deep water or floating) aman paddy is the major crop, but aus paddy and jute can also be grown. "Lowland" (nichu jumi) is land normally flooded up to six to twelve or fifteen feet

> deep in the monsoon season. Broadcast aman paddy is the only crop that can be grown. Some farmers also recognize "bottom land" (khoj jumi), land too deeply flooded (more than 12–15 feet) for even deep water aman varieties to be grown, but suitable (in some cases) for boro paddy to be grown during the dry season. Depth and duration of flooding of course, is not the only land characteristic important to cropping, but it is certainly one of the most important considerations for use of some areas in Bangladesh. (Brammer, personal communication *in* Olson, 1977)

Within the Hanunoo system of swidden agriculture in the Philippines, soils are distinguished according to at least eight criteria: 1) moisture content, 2) sand content, 3) rock content, 4) general texture, 5) firmness, 6) structure, 7) structure in the wet season, and 8) color (Conklin, 1959). Expecting peoples with this degree of sophistication to adapt to another system would be time-consuming at best. Malaysian farmers categorize soils in part on the basis of taste. These include "sweet" *(tanah payau),* "neutral" *(tanah tawan)* and "sour" *(tanah masan)* soils, and the classifications correlate significantly with pH levels (Weinstock, 1977). In Liberia, preliminary studies of traditional rural technologies for determining soil fertility and crop suitability among coastal and highland farmers indicate that significant judgments are made using indicators such as the physical appearance of earthworm feces, the color of "bug-a-bug" (termite) mounds, the type and density of vegetation on uncleared land, and the presence and condition of wild varieties of cultivated species. Besides such on-the-spot observations, "natural experiments" are conducted by, for example, noting the speed with which certain types of Mango seeds germinate after falling to the ground. As might be expected, such indigenous soil science is much more developed and reliable with regard to traditional subsistence crops than it is for more recently introduced cash crops (Myers, 1981).

Local knowledge should not be slighted in our effort to transfer SRI information. It should be remembered that over some 15 years the Soil Science Society of America has been revising and redefining words in order to produce its *Glossary of Soil Science Terms* (SSSA, 1978). Such narrowly focused language is unlikely to be understood without a lengthy apprenticeship or "in-training" period. As David Edwards points out regarding Jamaican farmers' knowledge concerning their soils: "Not surprisingly, much of their knowledge of these topics was clothed in a language different from that commonly employed by the soil scientist." Nevertheless, their sophistication is considerable.

> They referred to 'wash' rather than erosion. They said that rainfall water washes away the 'fat' or 'gum' (top soil), which is the best part of the soil and this has the effect of 'pooring' the land so that it becomes 'tired' and 'worn out.' The farmers also realized that most of the wash can be prevented in various ways. Sloping 'bare ground' can be covered by the vegetation of close-growing crops. Grass is particularly good; it rests the tired land. Tree crops help because their roots hold the soil and some shed leaves which form a protection layer on the ground. Mulching is commonly recognized as having a similar effect as well as 'feeding the land' and 'keeping it cool.' Trenches across the slope reduce damage by slowing down the water, and the fat or 'manure' deposited in them can be thrown back on to the ground above. Other obstructions to the flow of water are also recognized as an aid in reducing the rate of erosion (Edwards, 1961).

Coupled with such understanding, concepts such as the "hot" or "cold" nature of soils and other indicators of soil chemistry and potential fertility could well be utilized. In Malaysia, certain vegetation is understood to indicate such factors.

> The *kedudak* bush indicates a high level of aluminum in the soil; the tree *pohon bakan* indicates an acid soil with stagnant standing water; and *lalang* grass *(imperata cylindrica), keriang* berry bushes, and the cashew tree are indicators of low fertility soils. (Weinstock, 1977)

The correlation of certain types of vegetation with soils makes possible other methods of SRI information transfer.

Iconographic alternatives

In the United States there has been a tradition of using certain visual symbols to indicate actual or potential agronomic production on maps designed for popular use. These have included whole and partial ears of corn, heads of wheat, and other crops, keyed in the legend to thousands of bushels per symbol. Other possible symbols could include typical vessels used to store a particular crop, such as the kind of granary commonly built to store rice, a specific kind of pottery jar, or whatever. Suitability can be indicated in similar ways. Besides information about specific crops, symbols such as a recognizable or a stylized cashew tree or *pohon bakan* might be used in the Malaysian case, for example, to indicate potential problem sites and explain their nature quickly to participants. In many areas we also find types of soils correlated with specific weeds. In such cases, if the weeds could not be graphically represented, it might be worth considering naming that soil series (at least in local map legends) after the weed, and then giving other taxonomic designations in formal reports. With a minimum of effort such symbols and concepts could be made part of SRI information dissemination.

Other aspects

Research into other cultures by social scientists can reveal a number of mechanisms for more efficient information transfer. These could include a number of folk classification systems (Conklin, 1972). Also, in a particular society there may be locally significant *types* of landmarks that would minimize the time needed for people unfamiliar with printed maps to orient and locate themselves. There may be traditional ways of indicating spatial relationships, the travel of the sun, elevation, etc. (Gladwin, 1970). Any of these might be a great help in facilitating map use as an aspect of understanding and participation.

There are also a number of other psychological and psycho-physiological variables that might be taken into account (Phillips, 1977). In all of these areas, however, the paramount consideration is maximizing the meaningfulness of the communication to its audience.

A MOMENTARY SUMMARY

This paper cannot end with a conclusion, but with a recommendation. It presupposes that the reason for SRI information transfer on large-scale or local project levels is to facilitate effective and just planning and implementation of development projects, and

that this can only be accomplished through active participation in the planning and implementation process by the farmers who will ultimately reside in the area. Active participation can be maximized by culturally matching or interfacing SRI information (and other data) to the culture of the participants involved in the planning process. Subsequent to the delivery of this paper, major works edited by Chambers (1979), and Brokensha et al. (1980), have appeared which explore other theoretical and practical dimensions of the complementarity of Western science with indigenous science systems. Such applied anthropology programs, linked with and mediated through indigenous, traditionally based institutions of formal and nonformal education, promise a much greater degree of participation in planning and development than has heretofore been achieved (Conlin, 1974). It also may make possible much more fertile collaboration between traditional agriculturalists and modern scientists, with each group considering themselves the beneficiary.

LITERATURE CITED

Bornstein, M. H. 1975. The influence of visual perception on culture. Amer. Anthro. 77:774–798.

Brokensha, D. W., D. M. Warren and O. Werner. (eds.) 1980. Indigenous knowledge systems and development. Univ. Press of America, Lanham, MD.

Chambers, R. (ed.) 1979. Rural development: Whose knowledge counts? IDS Bulletin. 10(2):1–59.

Conklin, H. C. 1959. Hanunoo agriculture: A report on an integral system of shifting cultivation in the Philippines. FAO Forestry Development Paper No. 12. FAO, Rome.

Conklin, H. C. 1972. Folk classification: A topically arranged bibliography of contemporary and background references through 1971. Department of Anthropology, Yale University, New Haven, CT.

Conlin, S. 1974. Participation versus expertise. Int. J. Comp. Soc. 15(3–4):151–166.

Edwards, D. 1961. Report on an economic study of small farming in Jamaica. Institute of Social and Economic Research, University College of the West Indies.

Gladwin, T. 1970. East is a big bird: Navigation and logic on Puluwat Atoll. Harvard Univ. Press, Cambridge, MA.

Moran, E. F. 1976. Agricultural development in the trans-amazon highway. Latin American Studies Working Papers, Indiana University, Bloomington, IN.

Myers, D. 1981. Traditional soil survey techniques used by Liberian farmers. Bural Development Institute Mimeo. Cuttington Univ. College, Suacoco, Liberia.

Olson, G. W. 1977. Training key people in soil survey interpretations in Southeast Asia. Agronomy Mimeo 77–15. Dept. of Agronomy, Cornell University, Ithaca, NY.

Phillips, R. J. 1977. Making maps easy to read — a summary of research. Prepublication manuscript, delivered at the Processing of Visible Language Conference, Eindhoven, 5–8 September 1977. Department of Psychology, University College, London.

Saunders, R. 1977. Traditional cooperation, indigenous peasants' groups and rural development: A look at possibilities and experiences. Unpublished World Bank background paper.

Soil Science Society of America. 1978. Glossary of soil science terms. Soil Science Society of America, Madison, WI.

Tendler, J. 1976. Inter-country evaluation of small farmer organizations. Final report. USAID, Washington, D.C.

Weinstock, J. 1977. Indigenous soil classification. Unpublished manuscript, cited by permission of author.

Presentations of Soil Resource Inventory Data

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Soil survey reports are potentially the most useful source of land resource information available. Their actual utility depends not only on the design and technical reliability of the survey, but also on how the data are presented. This paper notes a variety of maps, reports, and techniques used to deliver resource inventory data to those who make decisions about land use. Graphic methods of data presentations are described.

A checklist developed at Montana State University lists 1,400 factors that might be included in a biophysical land resource inventory (Platenberg, Montagne, and Nielsen, 1974). Nearly one-fourth of the factors can be estimated from soil survey reports. No other commonly available source provides as much information. Renowned planners, Ian McHarg and Phillip Lewis, agree that few, if any, inputs to a land use plan are more important than a soil map and report.

ACTIVITIES, PRODUCTS, AND USERS OF A SOIL RESOURCES INVENTORY

Figure 1 schematically represents the activities, products, and users of a soil resources inventory process. The products column begins at the bottom with technical papers on soil genesis, proceeds upward through data banks, soil classification systems, basic land resource maps (at several scales), interpretation guides, and culminates at the top with maps showing potentials and hazards for various land uses. Products at the top of the column are in the greatest demand by the largest number of users. Inventory data move primarily upward through the soil inventory process but some informational items are presented at various levels (laterally in Figure 1) to specialized audiences. Following are brief descriptions of products and some comments on their effective presentation to users. Illustrations are drawn largely from experiences in Montana.

Technical papers

Research and technical papers on soil genesis and morphology provide basic knowledge that facilitates classification and mapping. Publication is usually in technical journals directed to professional soil scientists and a few profiles and landscapes add much to the effectiveness of journal articles and benchmark soil monographs as well as to public presentations on land use potentials and hazards.

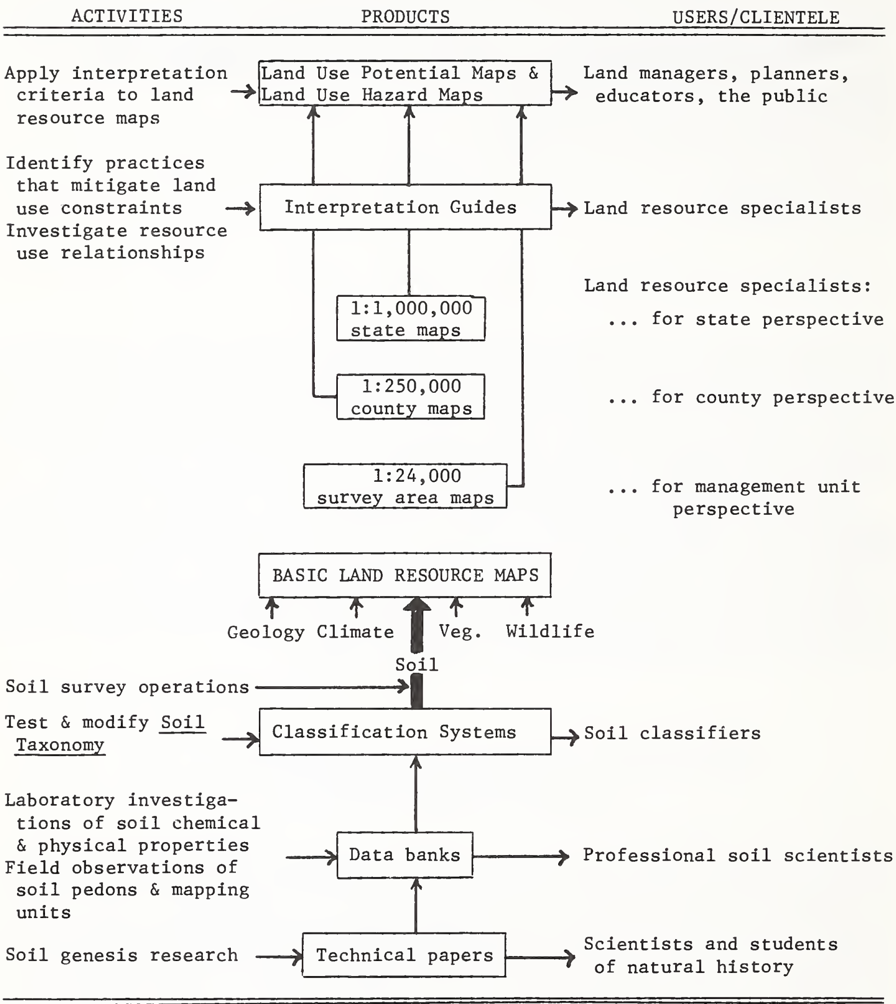


Figure 1. Activities, products and users of soil surveys for technology transfer and land use decision making. Modern soil survey reports present much of what is noted in the products column but most exclude maps showing land use potentials and hazards.

Data banks

In the soil resource inventory process, data accumulates from innumerable field observations and laboratory tests. These data are presented to other professionals in soil pedon descriptions and soil investigations reports. Coded data are exchanged on computer cards, magnetic tapes and directly by telephone hook-up on computer terminals. This massive collection is essentially a soil data bank, drawn upon for purposes of classification, mapping and evaluating land use potentials and hazards. Electronic computers can be powerful tools in processing and presenting these data. We record data in the field on mark-sense forms. Computers are programmed to print out descriptions of soil pedons and mapping units and rate soil limitations as "slight," "moderate," or "severe" for many potential uses (Decker, Nielsen, and Rogers, 1975). The ratings are based upon criteria developed by the SCS (Soil Conservation Service). The results appear as typewritten descriptions and tables. Processing and display of laboratory data are also automated.

Computers are used to store, process and print out soil pedon descriptions on an operational basis for all new surveys in Montana. The system is used routinely in university classes. SCS has proposed a national code system for computer storage and retrieval of soil pedon data and improved mark-sense forms for encoding data being tested.

Soil classification

Classification systems define kinds of soils that can be mapped and that have predictable sets of soil properties. *Soil Taxonomy* (USDA, SCS, 1975) illustrates a documented system that facilitates the exchange of ideas about soils in different geographic areas. This system is readily adapted (using soil phase concepts) to recognize features that are important for local evaluations of soil potentials. The system can be modified as new knowledge of soils is obtained.

Basic land resource maps

Inventory data are presented at several levels of detail. Several states have chosen 1:1,000,000 scale to give a stateside perspective, 1:250,000 for a countrywide view, and 1:24,000 for operational planning and decision making.

In planning for agricultural development there is a need to identify environmentally analogous areas where a particular cropping practice will give the same results. Locating analogous areas is a first step in transferring research conclusions within and among countries. Soil surveys may not be adequate in themselves for delineating environmentally analogous areas. Our work with land use planners and land managers has shown that more detailed information about climate, water, and other land resources is often needed. Dr. R. Dudal, Director of Soil Surveys for FAO and Executive Secretary of the International Soil Science Society, has stated that present soil surveys are inadequate to define land potential. Integration of basic land resource data with information on social, economic, and human resources is the most difficult task of all. A goal of at least two regional research projects in the United States is to develop more effective methods of disseminating soil resource data and interpretations. One approach has been to supplement general soil maps with companion maps of geology, topography, and ground water.

Interpretation guides

Basic maps of soils and other land resources are interpreted according to criteria which research and experience have shown influence land use potentials and hazards. Interpreting these maps singly and in combination is a multi-disciplinary task. Soil scientists should take an active role in this and can assist with socio-economic considerations as well.

Current interests in soil resource interpretations in Montana have included the following: fertilizer recommendations, outdoor recreation activities, nutrient and microbiological problems of waste disposal, taxation, zoning, definition of prime agricultural land, archeological studies, habitat identification for grizzly bears and other endangered wildlife species, livestock range potential, timber production, wilderness protection, barley and alfalfa production, definition of carrying capacity for land, route selection for transportation systems and utility corridors, planning and implementing strip mine reclamation, home site selection, ground truth for remote sensing, and saline seep identification.

Potentials and hazards maps

Many people, including planners, managers, and the general public, seek information about land and how potentials for agriculture, urban development, recreation or wildlife can be identified and realized. They are concerned about hazards of land use and how they can be overcome or avoided. Soil resource inventories do not provide all of the data needed to make maps showing potentials and hazards of land use, although they are usually the most useful single data source. Soil inventory data are most useful when presented in a form that is readily integrated with other critically needed data on both biophysical and socio-economic factors.

GRAPHIC METHODS OF DATA PRESENTATION

A soil map of Gallatin County, Montana, was published in 1931 (De Young and Smith, 1931). Hundreds of copies remained on shelves until 1970 when a supplemental report (USDA and Montana Agric. Exp. Stn., 1971) was prepared in which the use limitations of each soil were rated.

Color-coded soil limitation maps were prepared on transparent films using the ratings in the supplemental report. Colored felt-tip markers were used to identify the degree of limitations: green, yellow, and red for slight, moderate, and severe, respectively. Similar maps were colored to show soil limitations for cropping, roads, building foundation sites, sewage lagoons, septic tank filter fields, recreation areas, and other soil uses.

Groups of soil limitation maps were overlaid to show composite limitations for several uses. For example, one composite demonstrated that land being subdivided for housing had soils poor for homesites (roads, foundations, septic tanks) but good for crops.

Soil monoliths models, photographic prints, and 35 mm slides were used to illustrate soil limitations and related land use problems.

Dollar costs to overcome soil limitations were documented (Leeson, 1972) by talking with contractors and homeowners. Audiences were reminded that most soil limitations can be overcome with technological inputs. Extra costs were $1,900 for a home septic

tank and $60,000 per mile for inappropriately placed roads. The high cost of overcoming "severe" limitations sometimes prevented development.

These interpretations and display techniques increased demand for the original soil inventory and in a matter of months the entire supply was used.

Black and white maps were prepared from hand-colored maps and were reduced photographically for publication in newspapers. Most newspapers accept maps that accompany short articles on land use potentials and hazards and publish them without cost. Maps were published free and reached thousands of people. Publication in color is more effective but very expensive.

Interactive overlay techniques graphically integrate soil resource constraints with those imposed by geology, climate, vegetation, and other components of the land. Interactions of physical land capabilities with present and potential land uses are demonstrated. Overlays can show the location of roads, land ownership patterns, taxation districts, school districts, irrigation and drainage networks, marketing centers, and an almost endless number of social and economic factors that influence land use.

The shaded window display technique uses transparent overlay maps on which constraints for a particular land use are indicated in shades of red using color films.

A LOOK AT THE FUTURE

Efforts to communicate ideas about land potential to decision makers will certainly use more composite overlay maps. But overlays have some limitations. Eventually computers may be used to print individual soil constraint maps as well as composite maps in which each component is, in a sense, weighted according to its importance. The importance of each input (soil, climate, present land use, etc.) would be previously assigned by experts.

Land information systems will eventually incorporate computer graphic displays, remote sensing from satellites, computer data processing and systems analysis techniques. Integrated land capability maps will appear on television monitors. Planners will simulate compatible future uses for decision makers. Advisors and lay audiences will participate by changing value judgments involved in the land resource evaluations and by changing assumptions about future prices, populations, etc. Effects of these changes will be displayed immediately. Although these advanced systems will undoubtedly be common in the future, they are expensive, and examples of useful applications are still rare.

We have partially developed a *Computer Graphic System* for interactive display of land resource maps. The system produces plotter-drawn maps of Montana at a 1:1,000,000 scale. Data are manually encoded in about 40 man-hours per map using a point-change technique that stores data for 17,600 cells, each measuring 3 minutes by 3 minutes (about 8.2 sq. mi.).

The following data are being encoded from state maps: soils, length of frost-free season, date of first freeze, date of last freeze, potential evapotranspiration, annual precipitation, growing season precipitation, snowfall, a 50-year peak precipitation, R-factor, potential sediment yield, consumptive use, climax vegetation, chinook belts, and elevation.

WORKSHOPS AND A LAND RESOURCE INVENTORY HANDBOOK

A workshop on resource inventories and land use problems was conducted at Montana State University for county commissioners and planning board members from throughout the state. This workshop reaffirmed our conviction that much useful information about land resources remains unused because: (1) potential users are not aware of its existence, and (2) the information is in relatively unusable form.

In a formal evaluation of statewide county workshops on planning and regulation of land use, presentations on using soils information in planning were ranked by participants as 6.38 on a 1 to 7 scale (7 indicates information "very much worth my time"). The soils information received the highest mean rating and the highest number of positive open-ended comments for any of the 12 presentations delivered on various aspects of land use planning. A total of 107 requests were received for information on methods of producing overlay maps showing constraints of soils and other natural resources.

In press is a *Resource Inventory Handbook* that: (1) gives sources of information about land qualities and land use, (2) suggests common map scales and inexpensive techniques that citizen groups can use to display resource data in local newspapers, (3) tells how to interpret land resource data, and (4) explains how overlay maps can be prepared for public meetings. The handbook tells how resource information that is already available in files can be assembled to enhance land resource analyses.

CONCLUSIONS

The utility of soil maps is dependent upon effective methods of presentation. Composite maps showing potentials and hazards of specific land uses do present data effectively. Such maps include properly interpreted soil maps as the key component. Development of interpretation guides will constitute a major future thrust in soil science research. Clearly, a formal system is needed to appraise the relevance, quality, and adaptability of soil maps and other land resource inventory products.

LITERATURE CITED

DECKER, G. L., G. A. NIELSEN, and J. W. ROGERS. 1975. The Montana automated data processing system for soil inventories. Mont. Agric. Exp. Stn. Res. Rpt. No. 80. Bozeman, MT.

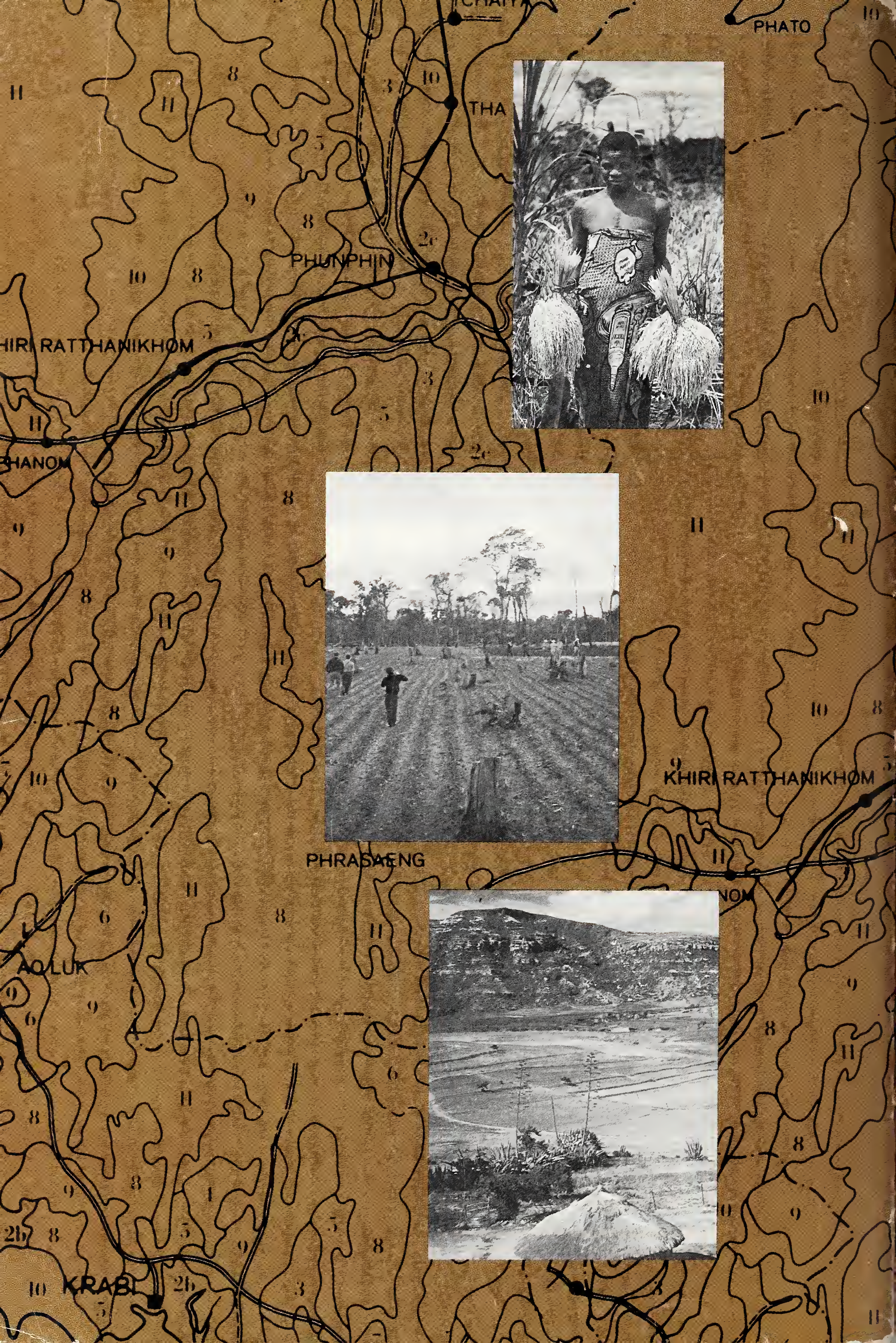
DE YOUNG, W., and L. H. SMITH. 1931. Soil survey of the Gallatin Valley area, Montana. Mont. Agric. Exp. Stn., Bozeman, MT.

LEESON, B. F. 1972. Soils and associated natural resources as decision parameters in the regional planning process. Ph.D. Thesis. Montana State Univ., Bozeman. (Diss. Abstr. 33(8):3421-B.)

PLANTENBERG, P. L., C. MONTAGNE, and G. A. NIELSEN. 1974. Natural resource inventory checklist. Mont. Agric. Exp. Stn. Capsule Info. Series No. 2. Bozeman, MT.

United States Department of Agriculture, Soil Conservation Service. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. U. S. Dept. Agric. Hndbk. 436. U. S. Government Printing Office, Washington, D.C.

United States Department of Agriculture and Montana Agricultural Experiment Station. 1971. Soil interpretations for land use planning and development in the Gallatin Valley area. Mont. Agric. Exp. Stn., Bozeman, MT.



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